Air Force Civil Engineer Center

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Former Williams Air Force Base

BRAC Cleanup Team Call
23 November 2015

Air Force Civil Engineer Center

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FORMER
WILLIAMS AIR FORCE BASE

Site ST012
Former Liquid Fuels Storage Area Remedial Action

BRAC Cleanup Team Call
23 November 2015

Site ST012 Update

- Steam Enhanced Extraction (SEE) Operations Progress
- Near-term SEE Operational Plan
- Review of Transition Criteria and EPA comments
- Review of TTZ Development and Adjustments relative to SEE and EBR

SEE System Operational Status Overview

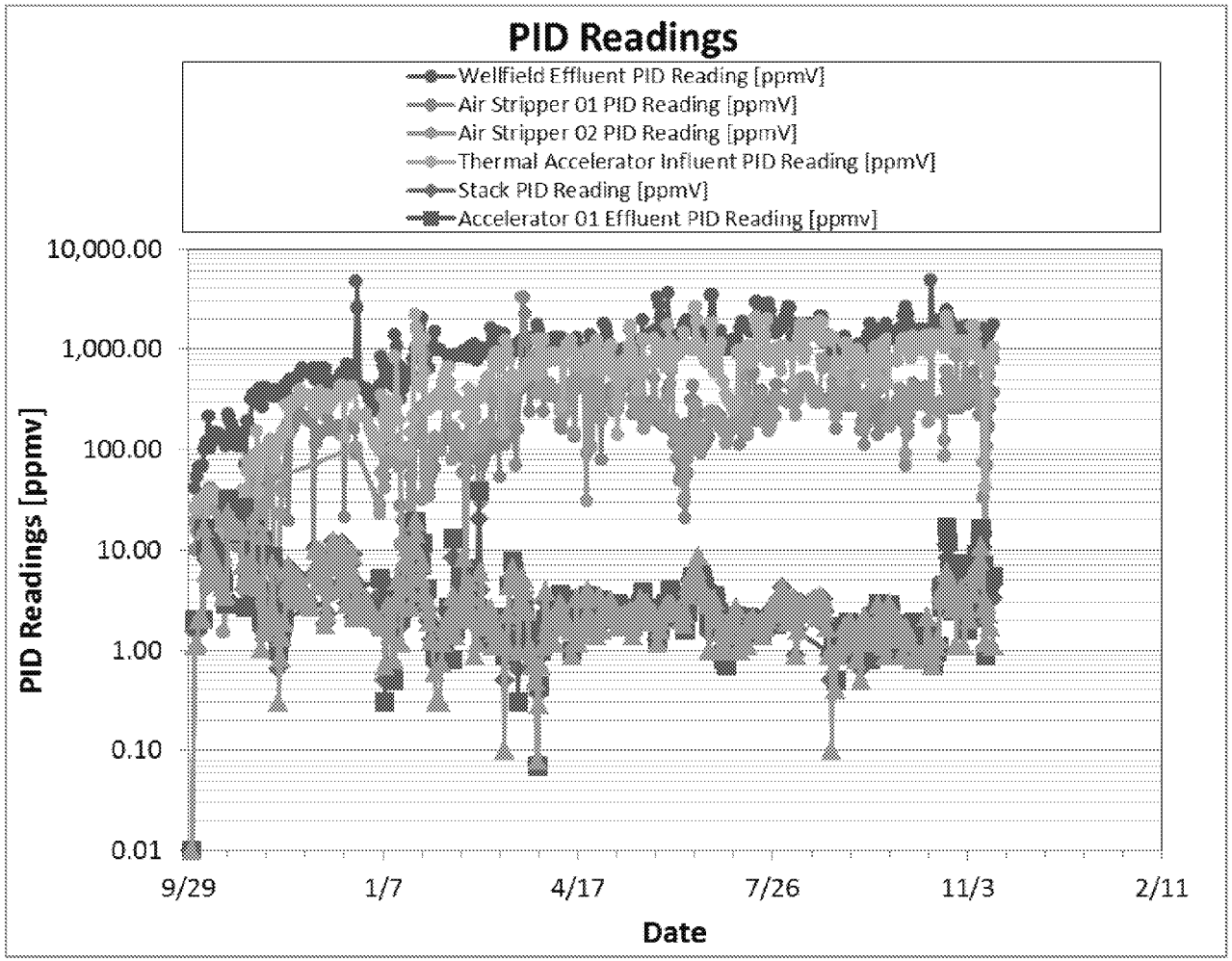
Site ST012 SEE System Status Summary (through 16 November)

	Value	Unit
Target Treatment Zone (TTZ) Soil Volume	410,000	cubic yards (cy)
Area	199,000	square feet (ft^2)
Upper Depth of Treatment	145	feet (ft) below ground surface (bgs)
Lower Depth of Treatment	245	ft bgs
Vapor Liquid Treatment Started	09/29/14	
Thermal Operations Started	09/29/14	
Last Process Data Update	11/16/15	
Last Temperature Data Update	11/16/15	
Estimated Total Days of Operation	422	days
Days of Operation	413	days
Days of Operation vs. Estimate	98	percent (%)
Estimated Total Energy Usage	11,343,000	kilowatt hours (kWh)
Total Energy Used	4,173,643	kWh
Used Electrical Energy vs. Estimate	37	%
Total Steam Injected	257.2	million pounds (lbs)
Projected Total Steam Injection	320	million lbs
Steam Injected Vs Projected	80	%
Total Mass Removed in Vapor Based on Photoionization Detector (PID) Readings	881,649	lbs
Total Mass Removed as NAPL	1,118,548	lbs
Average Daily NAPL Mass Removal Last Week	1,755	lbs/day
Total Vapor and Liquid Mass Removal (based on PID readings)	2,000,197	lbs
Average Power Usage Rate Last Week	481	kilowatts (kW)
Average Wellfield Vapor Extraction Rate Last	366	standard cubic feet per minute (scfm)
Average Condensate Production Rate Last Week	0.3	gallons per minute (gpm)
Average Water Extraction Rate Last Week	119	gpm
Total Water Extracted	64,296,041	gallons
Total Recovered Light Non-Aqueous Phase Liquid	170,251	gallons
Average Water Discharge Rate Last Week	149	gpm
Total Treated Water Discharge	84,898,000	gallons

ST012 SEE Operational Progress

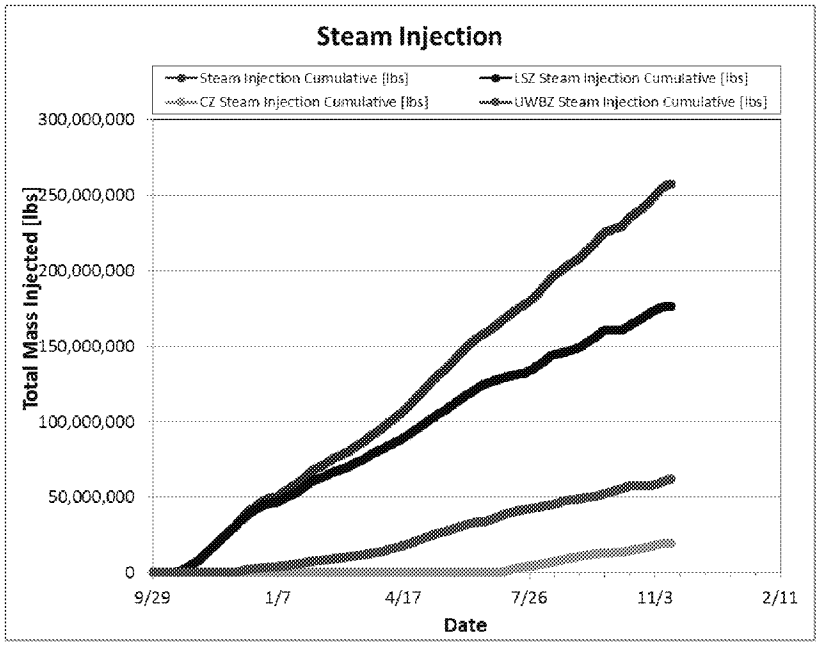
- **SEE System Operations** **6 October – 16 November**
  - Average liquid extraction rate of 116 gpm
  - Typically five to six eductor skids were online at a time
  - Average steam injection rates of 15,300 lbs per hour in the LSZ, 6,900 lbs per hour in the UWBZ, and 6,100 lbs per hour in the CZ
  - Thirty-two steam wells online – injection rates at wells have varied due to pressure cycling conducted in the CZ, LSZ and UWBZ
  - SEE discharge continues to meet compliance standards

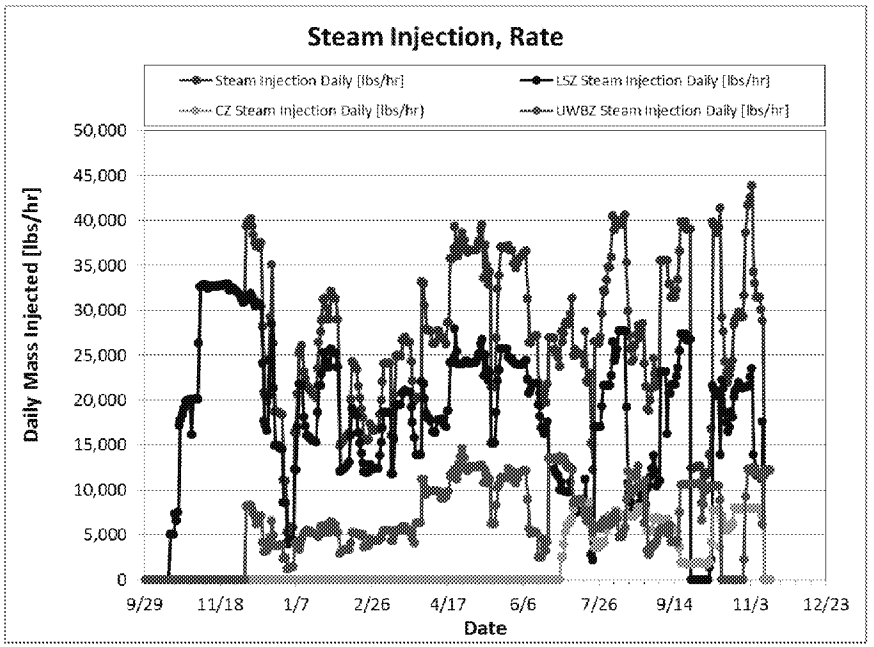
Site ST012 SEE System Photoionization Detector (PID) Readings



Vapors continue to be rich in organics

Site ST012 SEE Steam Injection

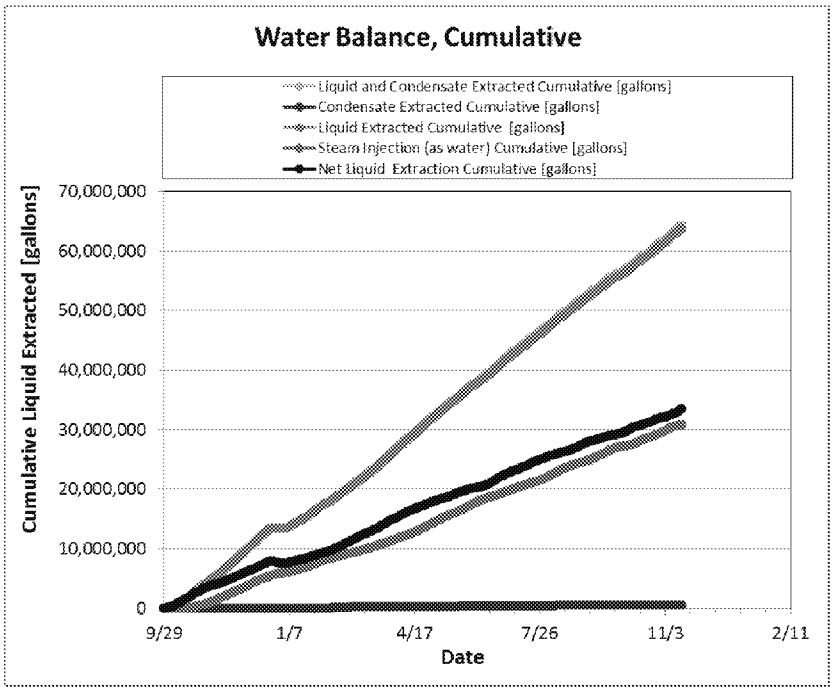


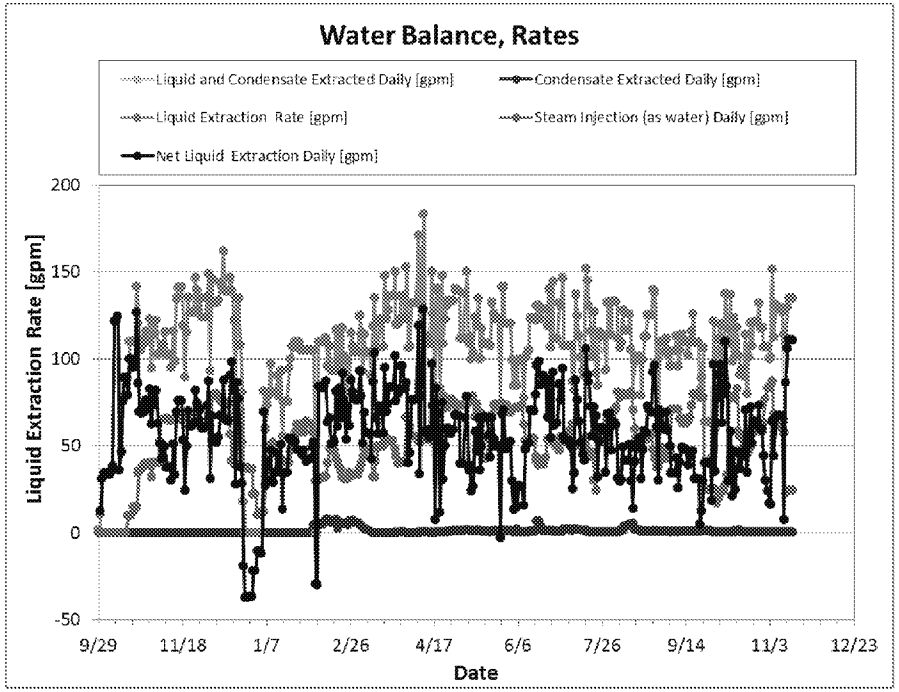


- **Current average steam injection (operational period ending 16 November 2015)**
  - **CZ: 2,000 lbs/hr ~ 4.0 gpm as water**
  - **UWBZ:11,200 lbs/hr ~ 22.4 gpm as water**
  - **LSZ: 4,100 lbs/hr ~ 8.2 gpm as water**

  Total steam injection rate equivalent to 34.6 gpm of water

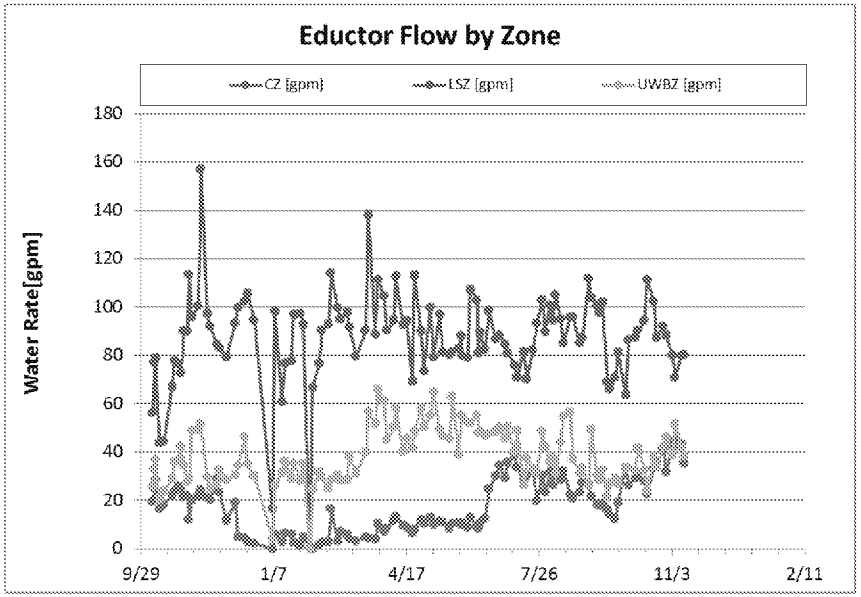
Site ST012 SEE System Water Balance

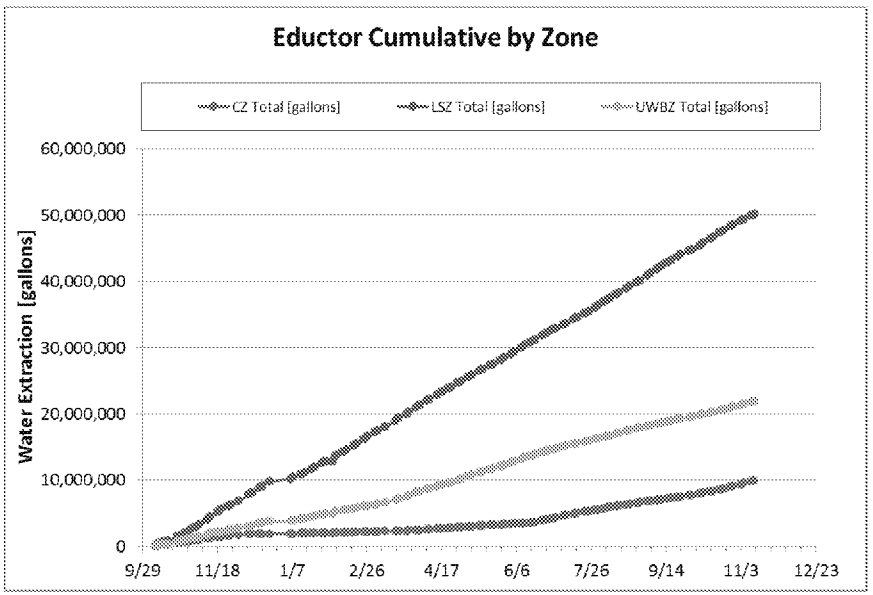




- **Currently, the condensate production rate is ~ 0.3 gpm**
- **Based on energy balance analysis, additional steam is likely being pulled into and condensing in the liquid extraction system; this steam extraction is not measureable and is not accounted for in condensate production**

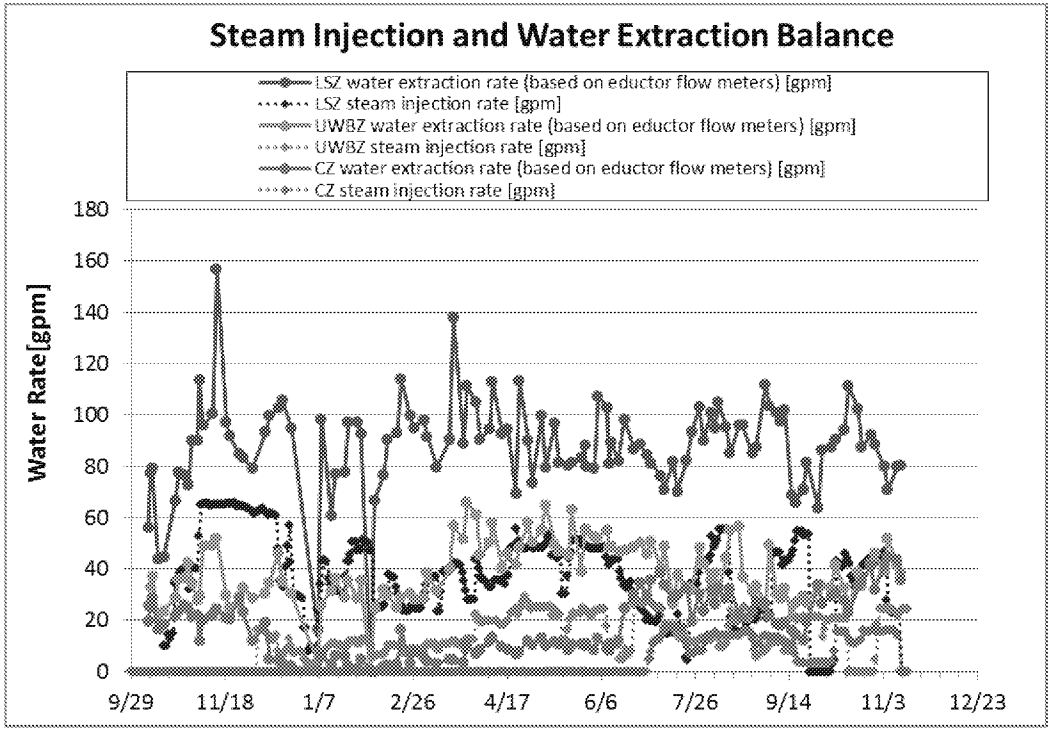
Site ST012 SEE System Water Extraction by Zone





- **Eductor extraction rates per zone are based on individual eductor feed and return meters**
- **Extraction: injection ratio for the week ending 16 November 2015: 3.4:1 based on average flows**
  - **CZ: 6 October– 16 November 2015 period: 2.4:1**
  - **UWBZ: 6 October– 16 November 2015 period: 2.3:1**
  - **LSZ: October– 16 November period: 2.5:1**

Site ST012 SEE System Injection/Extraction Balance

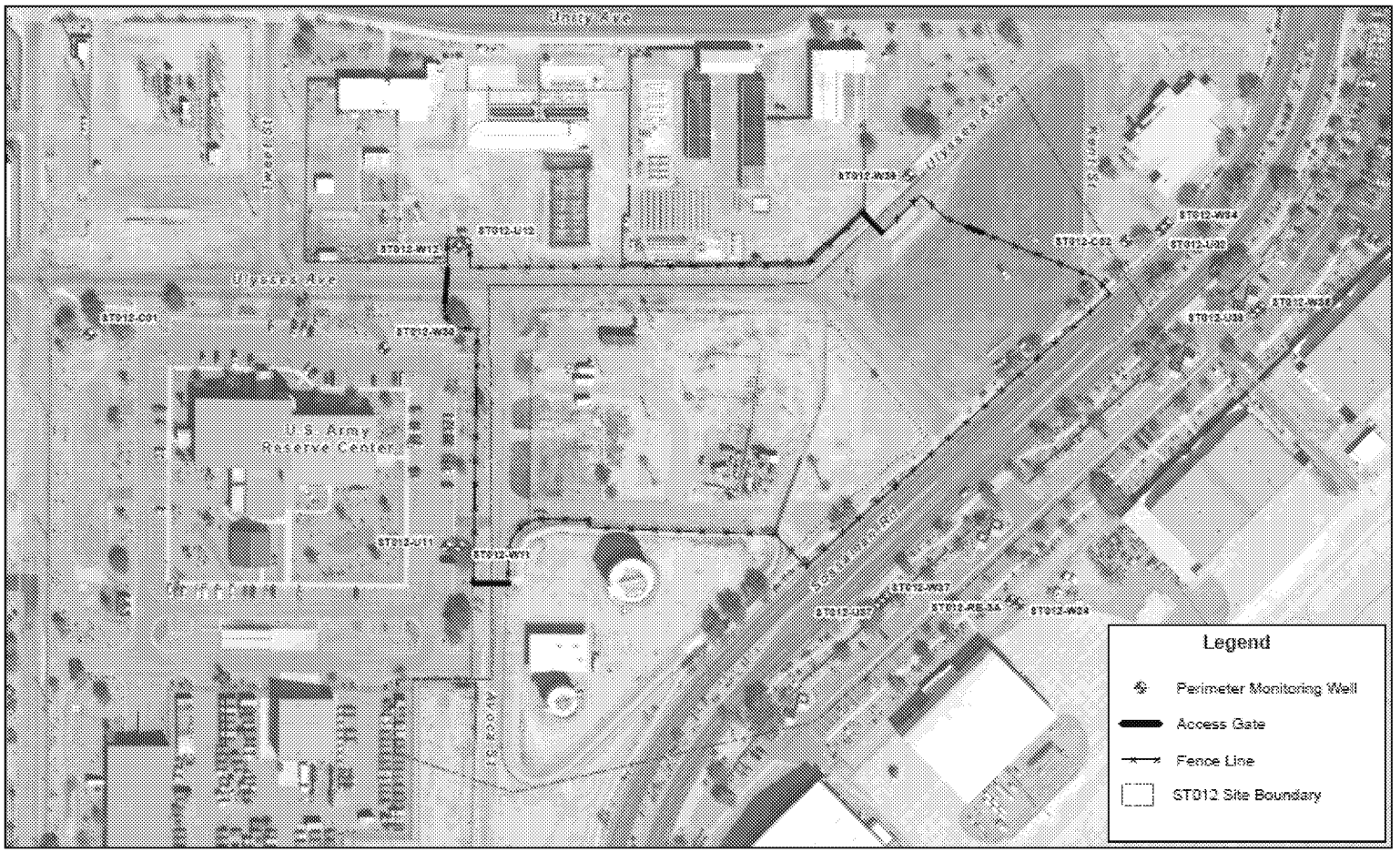


	CZ	UWBZ	LSZ
	[gallons]	[gallons]	[gallons]
Water extracted	9,944,000	21,931,000	50,199,000
Water injected (as steam)	2,319,000	7,431,000	21,137,000
Net extraction	7,625,000	14,500,000	29,062,000

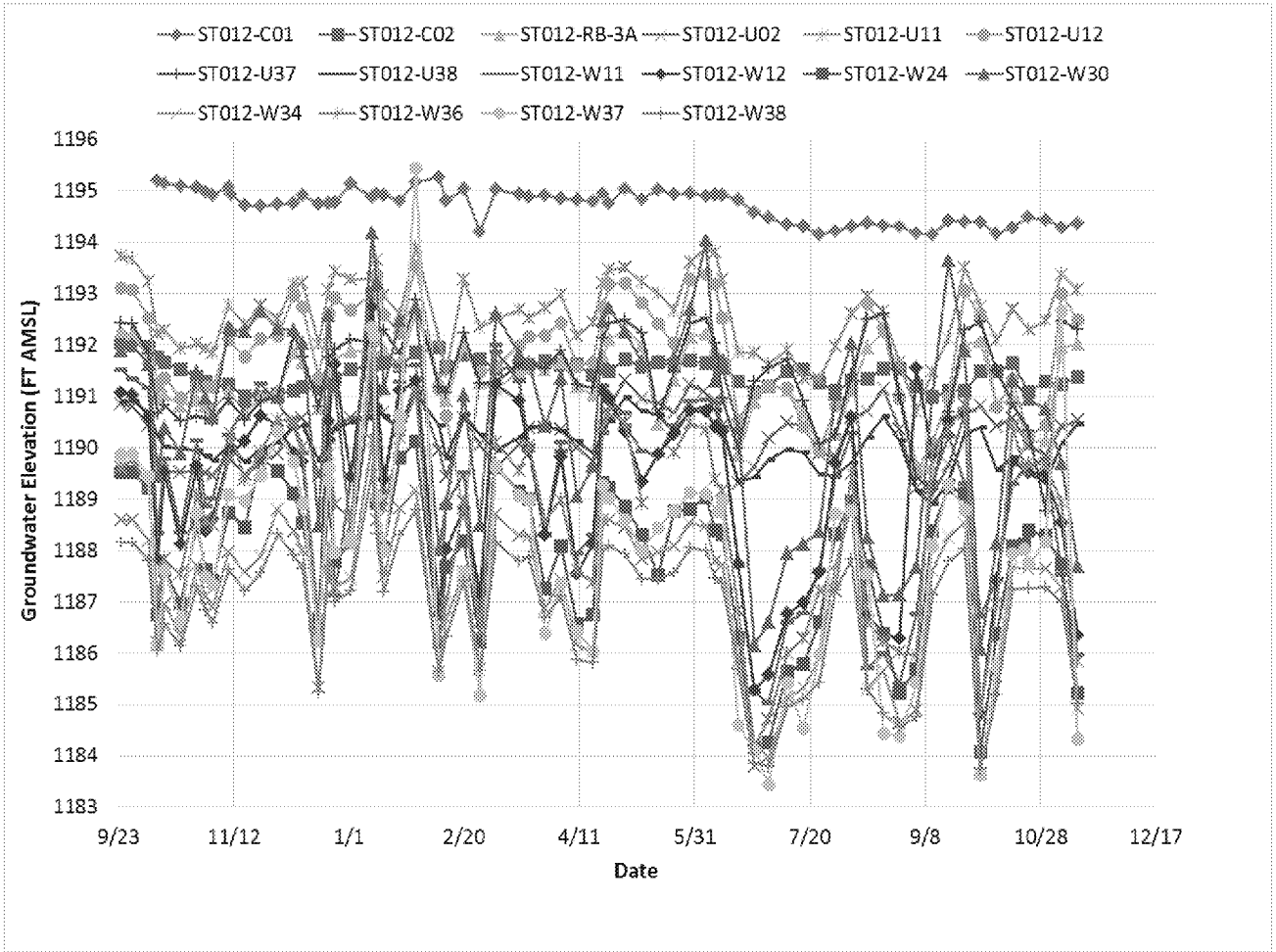
Note: water extracted to date per zone is based on individual eductor meters

ST012 Perimeter Groundwater Monitoring

Site ST012 SEE Perimeter Groundwater Monitoring Wells



Site ST012 SEE Perimeter Groundwater Elevations



Water level increases are temporary

Site ST012 SEE Perimeter LNAPL Thicknesses (ft)

Monitoring Well	10/23/2015		10/30/2015		11/6/2015		11/13/2015	
CZ/UWBZ Wells	Before bailing	After Bailing	Before bailing	After Bailing	Before bailing	After Bailing	Before bailing	After Bailing
ST012-C01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-C02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UWBZ Wells								
ST012-U02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-U11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-U12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-U37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-U38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-RB-3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LSZ Wells								
ST012-W11	9.31	0.60	31.26	0.70	45.71	10.04	21.63	14.49
ST012-W12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-W24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-W30	0.17	0.17	0.15	0.15	0.13	0.13	0.00	0.00
ST012-W34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-W36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ST012-W37	15.68	4.80	14.55	3.31	4.39	0.20	82.36	17.94
ST012-W38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ST012 SEE to EBR Transition

Site ST012 Remedy

- **Review of Phased Groundwater Remedy:**
  - **"When the effectiveness of contaminant mass removal by SEE has diminished, the remedial action will transition to enhanced bioremediation. The criteria that will be evaluated for this transition will be developed jointly by the AF, EPA, and ADEQ as part of the Remedial Design/Remedial Action Work Plan" (excerpt from RODA2, Section 1.4)**
  - **"The evaluation for completion of thermal operations will be made between AMEC and TerraTherm and discussed with the AF, EPA, and ADEQ prior to termination of steam injection." (excerpt from RD/RA WP, Section 4.2.4, Transition to Enhanced Bioremediation)**
  - **"The specific methods for enhanced bioremediation will be established in consultation with EPA and ADEQ based on biological and contaminant conditions after SEE implementation." (excerpt from RODA2, Section 1.4)**

Site ST012 SEE System
SEE to EBR Transition Criteria

- Criteria established to evaluate when the effectiveness of contaminant mass removal by SEE has diminished:
  - Primary SEE to EBR Transition Criteria
    - Achieve target subsurface temperatures
    - Diminishing mass removal rates
  - Secondary SEE to EBR Transition Criteria
    - Completion of Pressure Cycling: Repeat until no additional significant increases in effluent vapor concentrations observed when steam pressure is reduced
    - Benzene Concentrations: Target benzene concentration of 100 to 500 µg/L range within the TTZ (interior of the TTZ)
    - Steam Injection: Used as a guideline to measure progress vs. design
- Criteria are based on principal of multiple lines of evidence. The criteria will be considered in total with the weight of evidence from these multiple lines being used for decisions. Individual compliance with each criteria is not absolute.

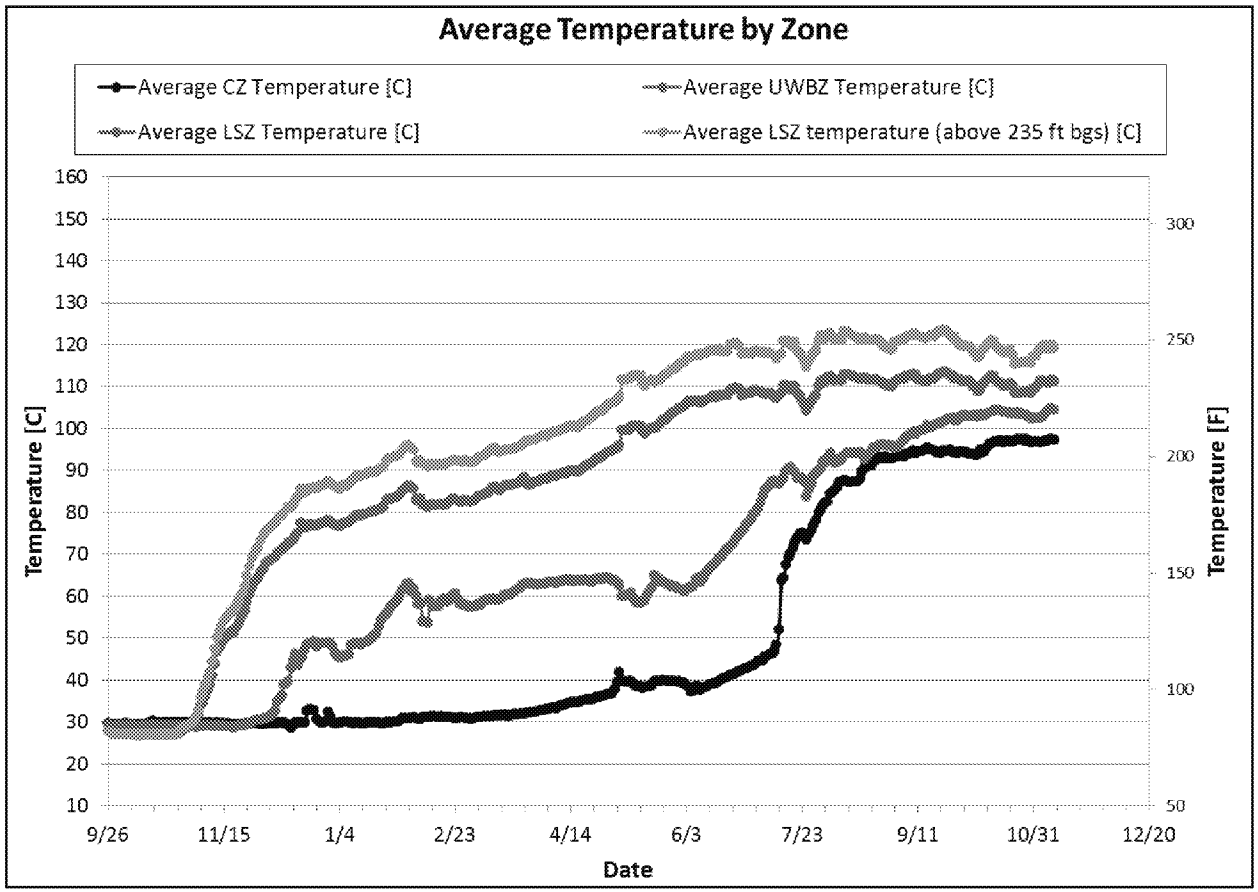
Subsurface Temperatures and Steam Breakthrough

EPA Comment

- ***Analysis: According to slide 20 from Oct 15, the target temperature for the CZ is ~ 100C, which has almost been met. The target for the UWBZ is ~114C, which has almost been met. The target for the LSZ is ~134C, which has not been met.***

Parameter	Target Criteria	Basis for Target Criteria	Description
Subsurface Temperature	Varies by Depth (higher boiling temperatures with depth – see Figure 5.3, in Appendix D of the RD/RAWP	Numerical thermal modeling of TTZs supported by depth-specific boiling points.	Efforts will be made during operations to inject steam throughout the TTZ to target achievement of boiling point temperatures for groundwater throughout the TTZ. A steam zone will be generated and maintained where possible with the goal of pushing steam across the TTZ to form a steam zone between injection and extraction wells, with breakthrough of steam demonstrated at extraction wells. It is anticipated that a steam zone will not be able to be created and maintained in the LPZ. Other areas of low permeability may also be discovered during operation that limit achievement of target temperatures. Operational adjustments will be made where possible to increase temperatures in such zones that are slower to reach target temperatures. The energy balance will be used to support evaluation of achieving the temperature goal. Shut-down of steam will only be considered after achieving boiling point temperatures throughout the TTZ with the exception of the LPZ and other potential areas of low permeability and provided that operational adjustments are made to attempt to achieve the temperature goal in areas that are resistant.

Site ST012 SEE
Average Temperatures by Zone



- **Average temperatures continue to increase in CZ and UWBZ**
- **LSZ temperature sensors 240 ft bgs and lower generally do not show steam temperatures**

CZ Target Treatment Temperature: ~100°C
UWBZ Target Treatment Temperature: ~114°C
LSZ Target Treatment Temperature: ~134°C

Site ST012 SEE TMP Maximum Depth-Averaged Temperature by Zone

Temperature Monitoring Point	Temperature Monitoring Point Maximum Depth-Averaged Temperature[1] (°C) During SEE Operations by Zone				
	CZ	UWBZ	LPZ	LSZ	LSZ (depths above 235 ft bgs)
TMP01	114.6	130.5	N/A	N/A	N/A
TMP03	N/A	N/A	137.5	110.2	117.4
TMP04	N/A	N/A	103.8	118.8	127.1
TMP05	102.0	N/A	N/A	N/A	N/A
TMP06	N/A	N/A	137.4	135.0	135.9
TMP07	N/A	N/A	134.6	137.2	140.2
TMP08	N/A	N/A	136.6	131.3	135.4
TMP09	N/A	N/A	132.5	134.1	139.3
TMP11	N/A	N/A	107.4	119.1	131.7
TMP12	75.3	89.9	121.8	121.4	131.3
TMP13	102.1	119.8	130.6	138.4	140.0
TMP14	N/A	N/A	133.6	124.3	136.3
TMP15	113.1	123.3	128.7	126.5	135.6
TMP16	N/A	N/A	126.7	120.4	131.0
TMP17	N/A	N/A	139.3	141.3	141.3
Maximum depth-averaged by zone[2]	**101.4**	**115.9**	**128.5**	**127.5**	**134.0**

If N/A, Temperature Monitoring Point has no sensors in that zone

[1] Temperature of the thermocouples across each depth zone are averaged for each TMP and each available time interval and then the maximum value of those averages throughout operations is listed in the table.

[2] Average of maximum depth-averages listed above for all TMPs in each zone.

- **Target treatment temperatures achieved in all zones (LSZ <235 ft bgs)**

CZ Target Treatment Temperature: ~100°C
UWBZ Target Treatment Temperature: ~114°C
LSZ Target Treatment Temperature: ~134°C

Site ST012 SEE
MPE Steam Breakthrough Achievement

Well	Well Location	Required to Reach Steam Temperature	Steam Breakthrough Achieved at MPE Temperature Calculated
CZ07	Perimeter	No	No
CZ08	Perimeter	No	No
CZ09	Perimeter	No	No
CZ10	Perimeter	No	Yes
CZ11	Interior	Yes	Yes
CZ12	Perimeter	No	Yes
CZ13	Perimeter	No	Yes
CZ14	Perimeter	No	Yes
CZ15	Interior	Yes	Yes
CZ16	Perimeter	No	Yes
CZ17	Perimeter	No	Yes
CZ18	Perimeter	No	No
CZ19	Perimeter	No	No
CZ20	Outside CZ	No	No

Well	Well Location	Required to Reach Steam Temperature	Steam Breakthrough Achieved at MPE Temperature Calculated
UWBZ01	Interior	Yes	Yes
UWBZ02	Interior	Yes	Yes
UWBZ04	Interior	Yes	Yes
UWBZ05	Interior	Yes	Yes
UWBZ06	Interior	Yes	Yes
UWBZ10	Perimeter	No	Yes
UWBZ17	Perimeter	No	Yes
UWBZ18	Interior	Yes	Yes
UWBZ19	Perimeter	No	Yes
UWBZ20	Dual Phase - Perimeter	No	No
UWBZ21	Outside UWBZ	No	No
UWBZ22	Perimeter	No	No
UWBZ23	Outside UWBZ	No	Yes
UWBZ24	Dual Phase - Perimeter	No	No
UWBZ26	Outside UWBZ	No	No
UWBZ27	Outside UWBZ	No	Yes

Well	Well Location	Required to Reach Steam Temperature	Steam Breakthrough Achieved at MPE Temperature Calculated
LSZ01	Interior	Yes	Yes
LSZ02	Interior	Yes	Yes
LZS04	Interior	Yes	Yes
LSZ05	Interior	Yes	Yes
LSZ06	Interior	Yes	Yes
LSZ08	Perimeter	No	Yes
LSZ11	Perimeter	No	Yes
LSZ12	Perimeter	No	No
LSZ13	Interior	Yes	Yes
LSZ14	Perimeter	No	No
LSZ15	Interior	Yes	Yes
LSZ16	Interior	Yes	Yes
LSZ17	Perimeter	No	Yes
LSZ28	Perimeter	No	Yes
LSZ29	Perimeter	No	No
LSZ30	Interior	Yes	Yes
LSZ31	Interior	Yes	Yes
LSZ32	Interior	Yes	Yes
LSZ33	Perimeter	No	Yes
LSZ34	Interior	Yes	Yes
LSZ35	Perimeter	No	Yes
LSZ36	Perimeter	No	Yes
LSZ37	Perimeter	No	Yes
LSZ38	Perimeter	No	Yes
LSZ39	Perimeter	No	No
LSZ40	Interior	Yes	Yes
LSZ42	Perimeter	No	Yes

- **Steam breakthrough has been achieved at all interior MPE wells**

Pressure Cycling and Mass Removal

EPA Comment

- ***Analysis: This criterion is nonspecific. The purpose of pressure cycling, and indicated in the statements above is to enhance volatilization of contaminants. It is not intended to improve mobilization and recovery of NAPL which may have been retarded by premature initiation of pressure cycling. Ideally, the bulk of NAPL should be removed first before initiation of pressure cycling as the finishing step. As long as NAPL is being recovered, steam injection should continue, then institute pressure cycling to remove the last of the volatiles. It is unfortunate that we did not discuss criteria for initiation of pressure cycling in the work plan.***

Parameter	Target Criteria	Basis for Target Criteria	Description
Completion of Pressure Cycling	Completion of multiple pressure cycles in each area	Pressure cycling has been demonstrated at other sites to improve mass removal beyond that achieved by uniform heating only.	Once the TTZ temperatures have stabilized, further mass removal improvement can be achieved by releasing steam pressure to cause volatile LNAPL constituents to rapidly vaporize for subsequent collection by MPE wells. The process of building and releasing the pressure is repeated until no additional significant increases in effluent vapor phase concentrations occur when steam pressure is reduced.

Pressure Cycling Status

- **Operational data reviewed to determine initiation of pressure cycling:**
  - **Multi-phase Extraction (MPE) Well Vapor Extraction Temperature**
  - **Temperature Monitoring Point Data**
  - **Calculated MPE Well Formation Temperature**
  - **Pressure cycling initiated to enhance benzene removal and to limit potential NAPL migration outside the TTZ**
  - **Pressure cycling status reviewed on 27 May 2015 BCT call prior to initiation and again on 24 June 2015 BCT call after it was initiated in the northern portion of the UWBZ. Pressure cycling status has been reviewed monthly since then on BCT calls**

- **Pressure Cycling Status by Zone:**

CZ			6/30/15					9/17/15		10/7/15			11/11/15
UWBZ		12/4/14	6/8/15	6/22/15	7/24/15	8/12/15	8/26/15	9/17/15			10/14/15	10/30/15	
LSZ	10/16/14		6/16/15		7/24/15	8/12/15	9/4/15		9/25/15	10/7/15			11/11/15

Pressurization
Depressurization

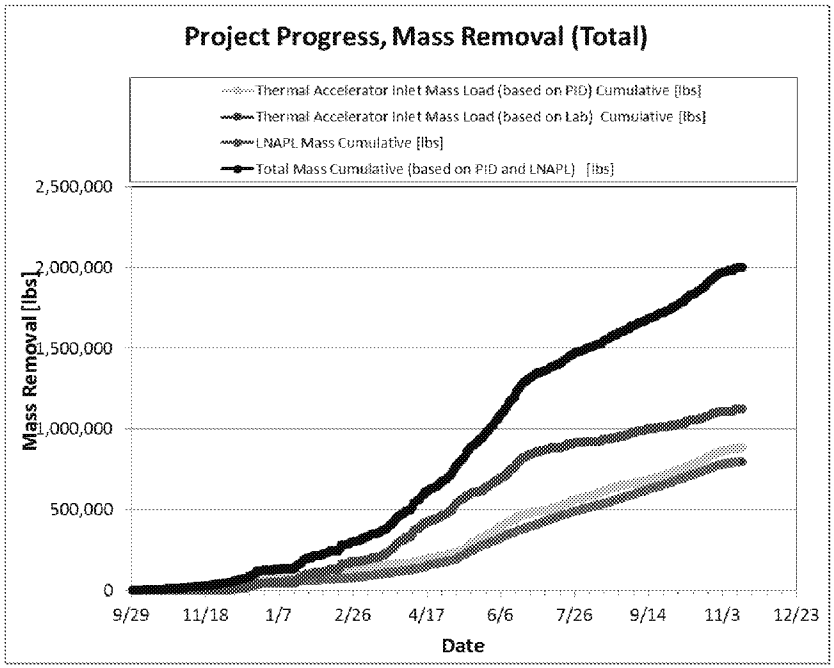
**Please note that dates in the table above are the dates that pressurizations or depressurizations were initiated*

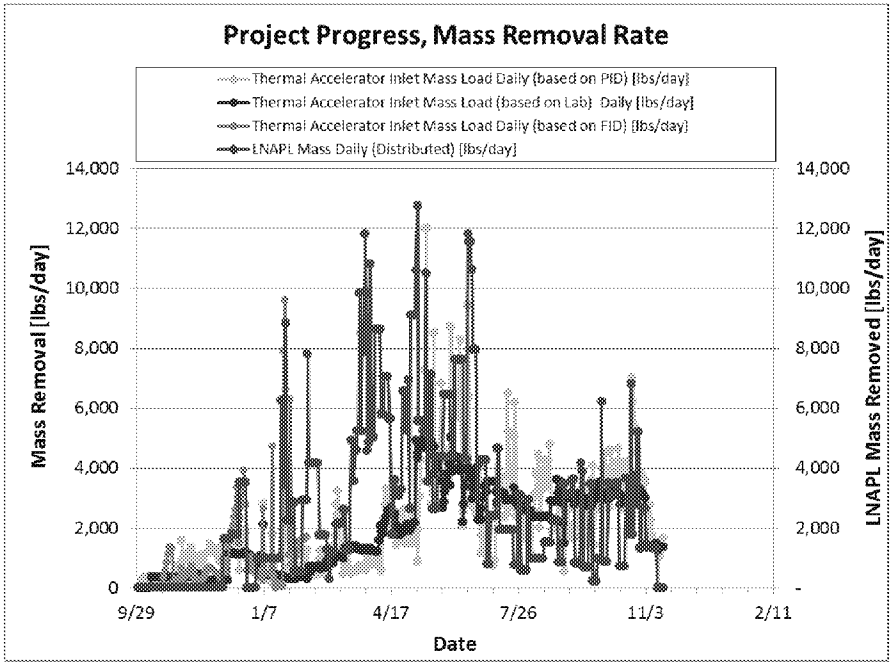
EPA Comment

- ***Analysis: Current LNAPL recovery is at 30% of peak removal rate; vapor recovery is 50% of peak removal rate; Criteria for termination of steam injection has not been met. EPA considers the criteria of 10% of the peak mass recovery to be high compared to the mass recovery rates that have been used to support thermal treatment termination at other sites. We cannot support termination of treatment when thousands of pounds of contaminant mass are being extracted daily.***

Parameter	Target Criteria	Basis for Target Criteria	Description
Mass removal	Less than 10 percent of peak removal rate	10 percent selected as an indication of significant decline in mass removal by SEE. This target is consistent with removal rate trends observed at other sites and provides some accommodation for the uncertain mass present and the uncertain peak extraction rate. The actual site-specific removal rate curve will be evaluated to confirm or adjust the appropriateness of this value to represent a condition of diminishing returns.	The rate of contaminant mass removal from the subsurface will play a major factor in determining when SEE is complete or sufficient. The mass removal rate will be closely monitored and will be optimized by using pressure cycling events. Toward the end of the operational period, the mass removal rates will be modest when compared to the peak removal rates (typically less than 10 percent of the rate observed at peak operations). Contaminant mass located around the perimeter of the TTZ may contribute a continuing source of mass for removal by the SEE system, which could mask the progress of mass removal within the TTZs, so the contribution of perimeter/interior extraction wells may be evaluated for mass removal towards the end of operations to identify any perimeter influx. Continued operation below the 10 percent of peak removal rate may be implemented depending on the significance of continued mass removal, the status of COC concentrations (e.g., benzene) in extracted fluids, and the need/ability for EBR to achieve further degradation based on data collected during the EBR field test.

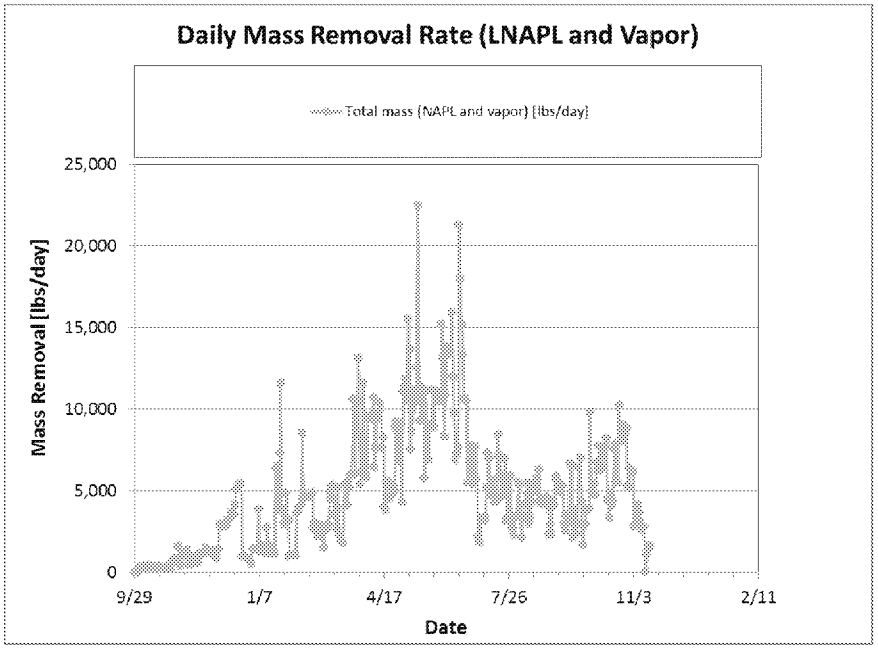
Site ST012 SEE System Mass Removal

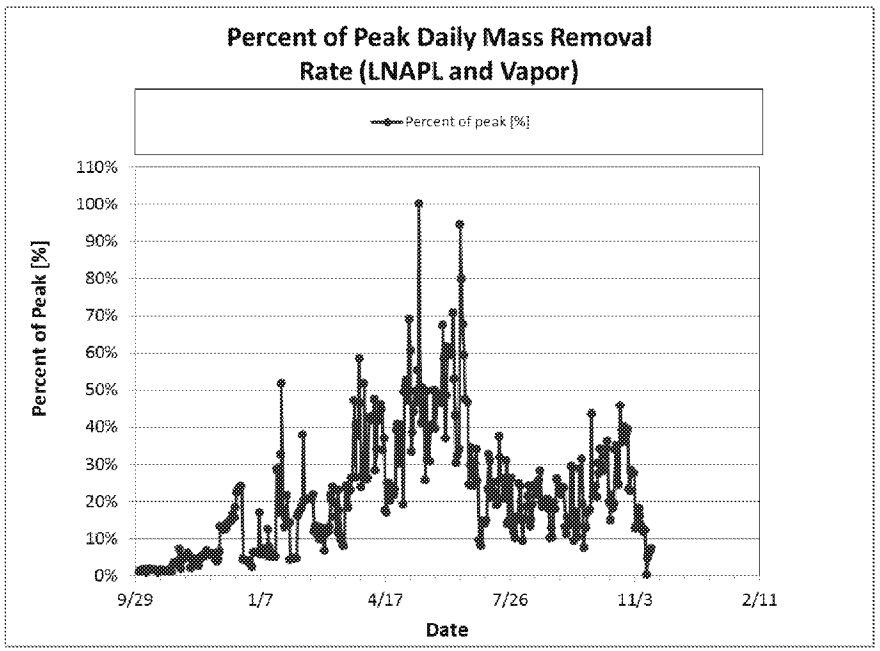




- **Total Contaminant Mass Removal: 2,000,197 lbs recovered**
- **An estimated 1,118,548 lbs (170,251 gallons) as non-aqueous phase liquid (NAPL)**
- **An estimated 881,649 lbs of mass (PID) removed in the vapor phase**

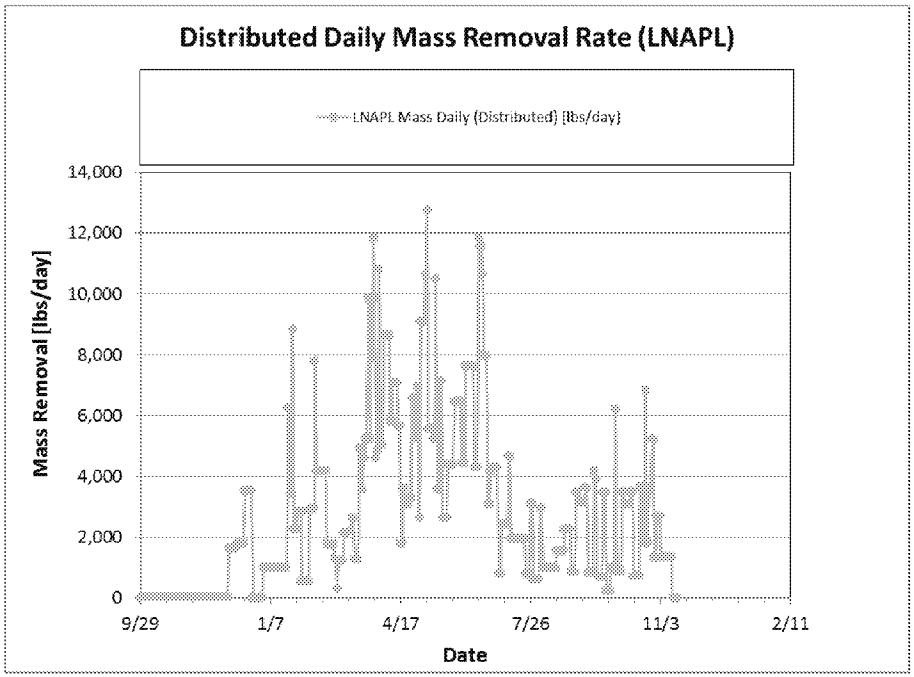
Site ST012 SEE System Daily Mass Removal

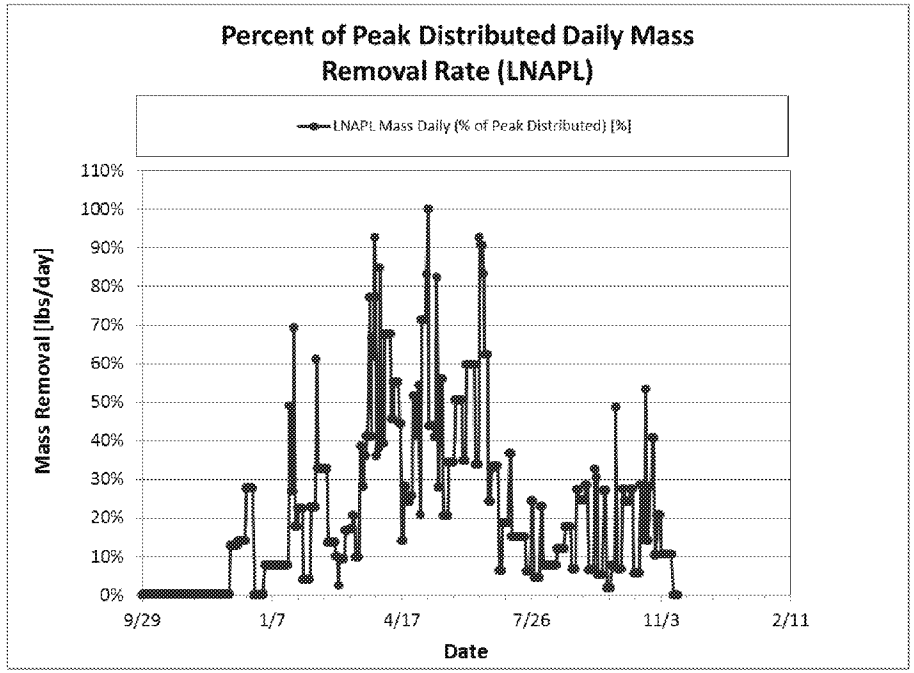




- **Mass removal target of ~10% of peak is appropriate for ST012 because of the follow-on EBR and natural attenuation planned**
- **Mass removal peaked on 14 May 2015 at 22,506 lbs/day**
- **Mass recovery has dropped to <10% of the peak**

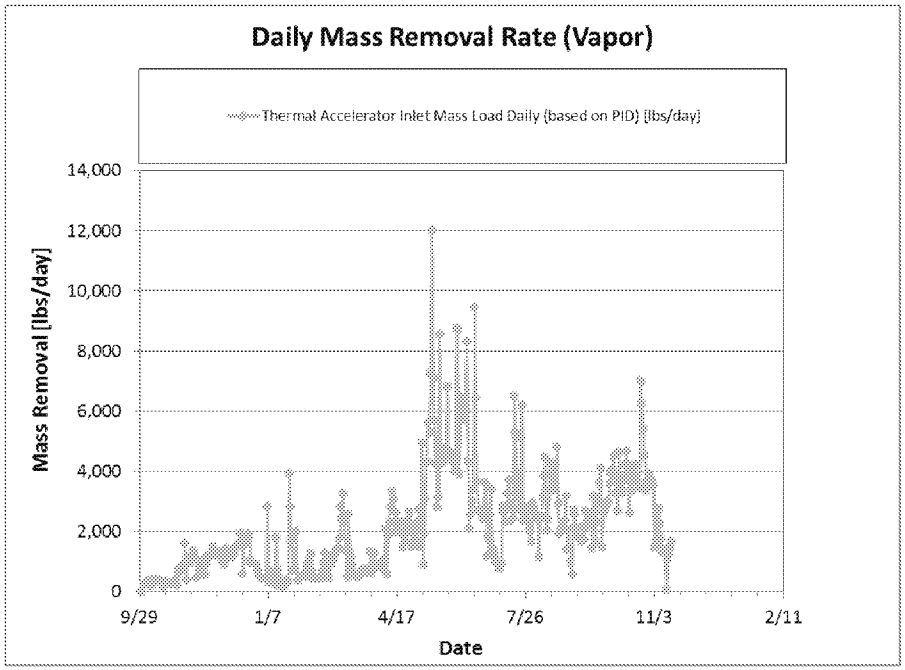
Site ST012 SEE System
Daily Mass Removal

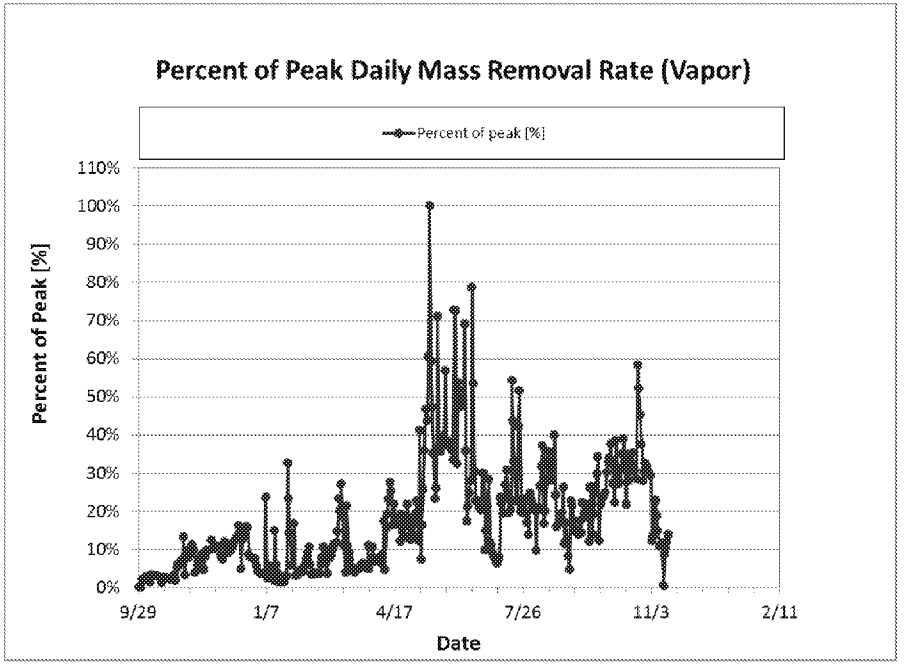




- Daily LNAPL mass removal peaked on 5 May 2015 at 12,760 lbs/day
- LNAPL recovery has dropped to ~10% of the peak

Site ST012 SEE System
Daily Mass Removal

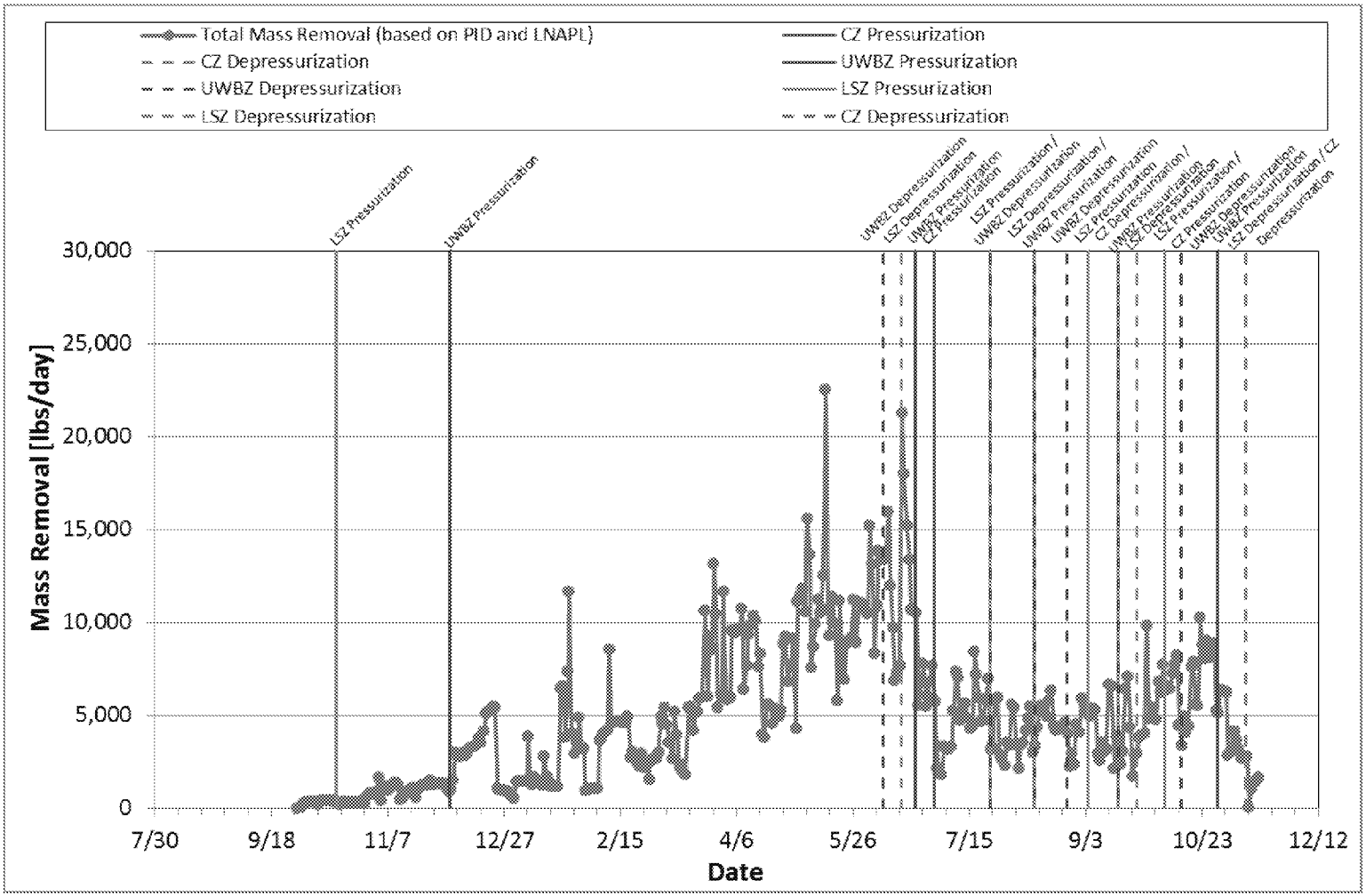




- **Daily vapor mass removal peaked on 14 May 2015 at 12,009 lbs/day**
- **Vapor mass removal rates have dropped to <15% of the peak**

Pressure Cycling and Mass Removal

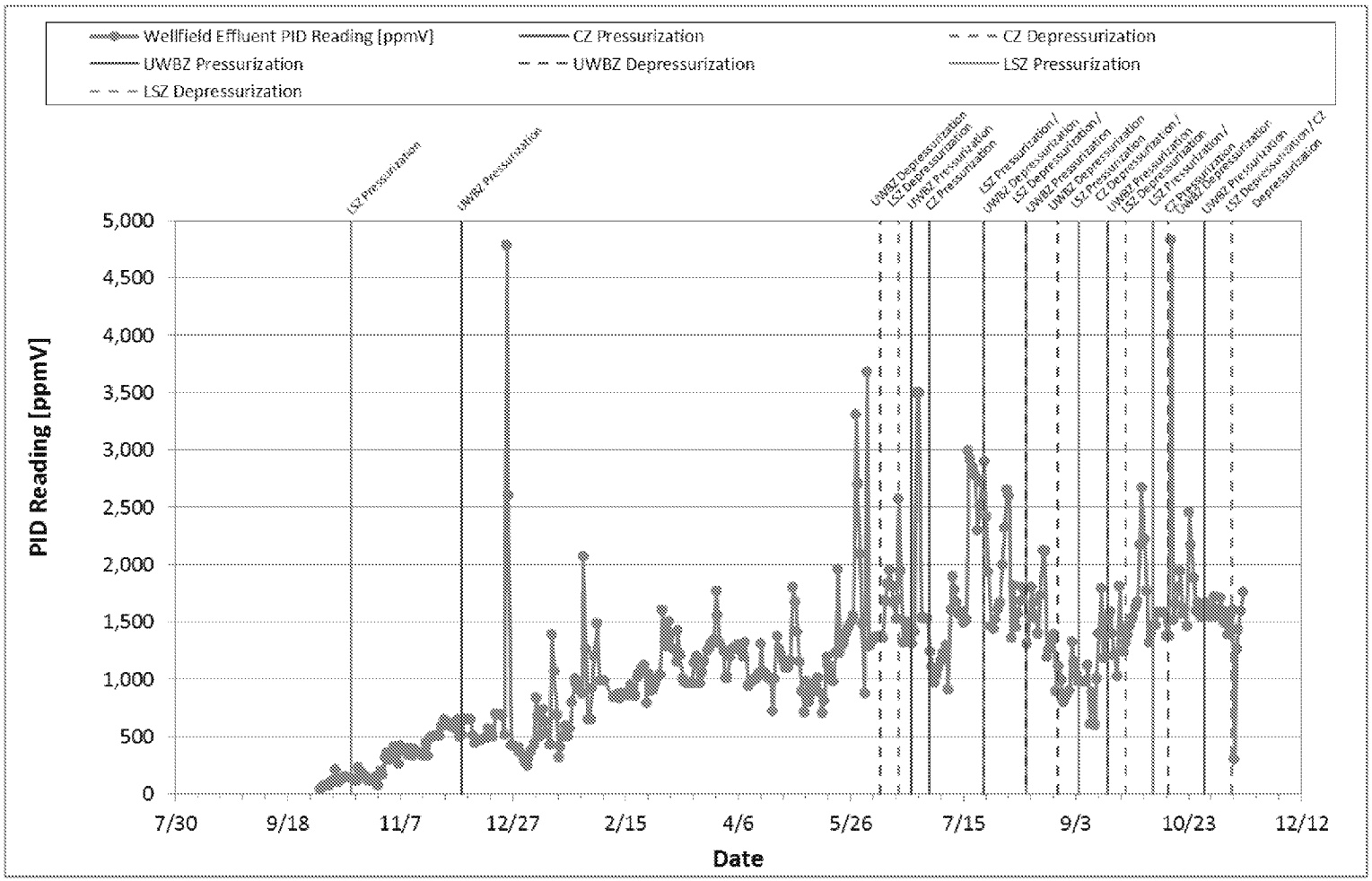
Mass Removal over Time



Peak mass removal occurred April – June 2015 (vapor and NAPL phases)

Pressure Cycling and Vapor Concentrations Over Time

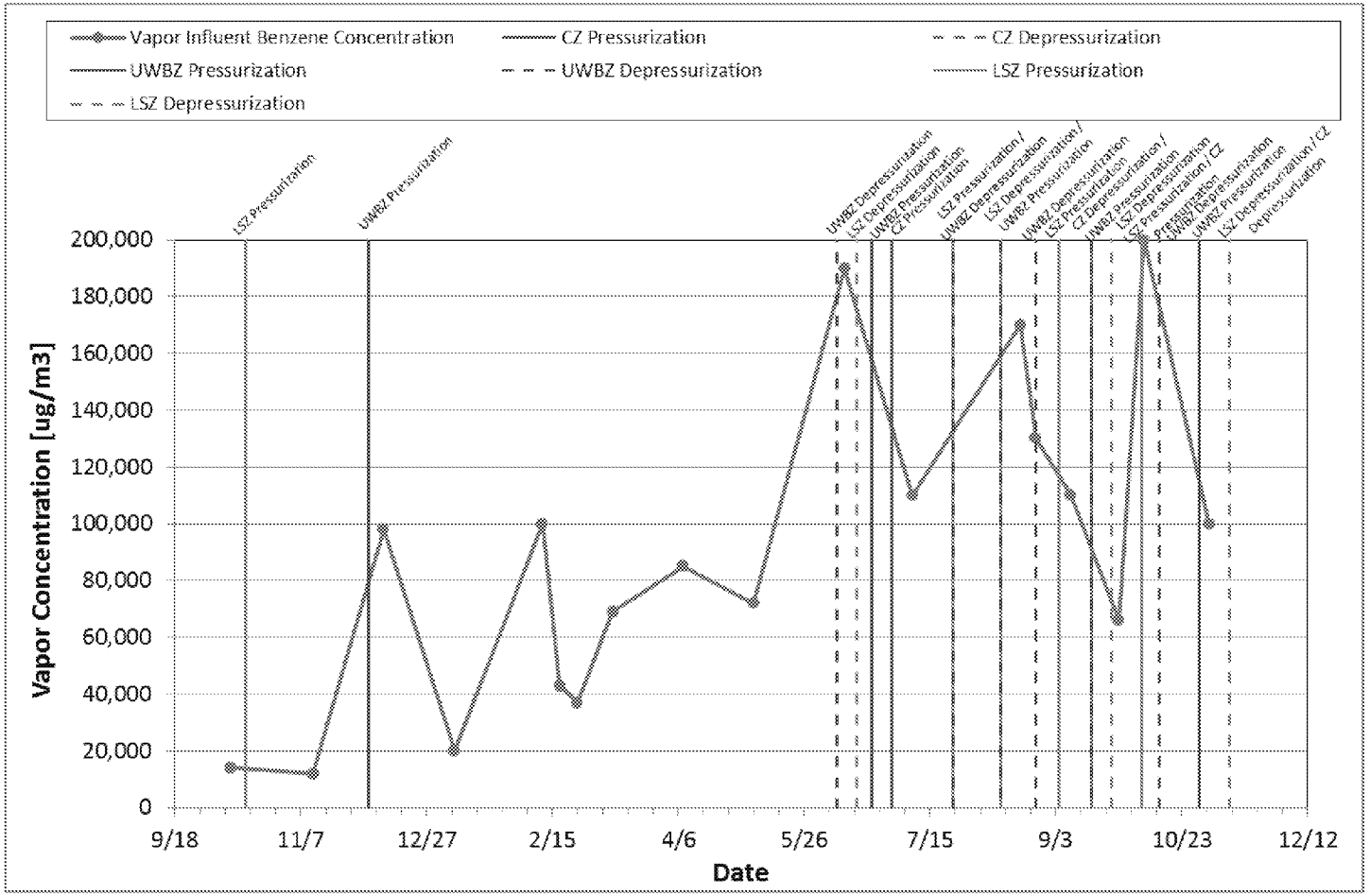
Wellfield Vapor Influent PID Concentrations over Time



Vapor phase removal has stabilized

Pressure Cycling and Benzene Vapor Concentrations Over Time

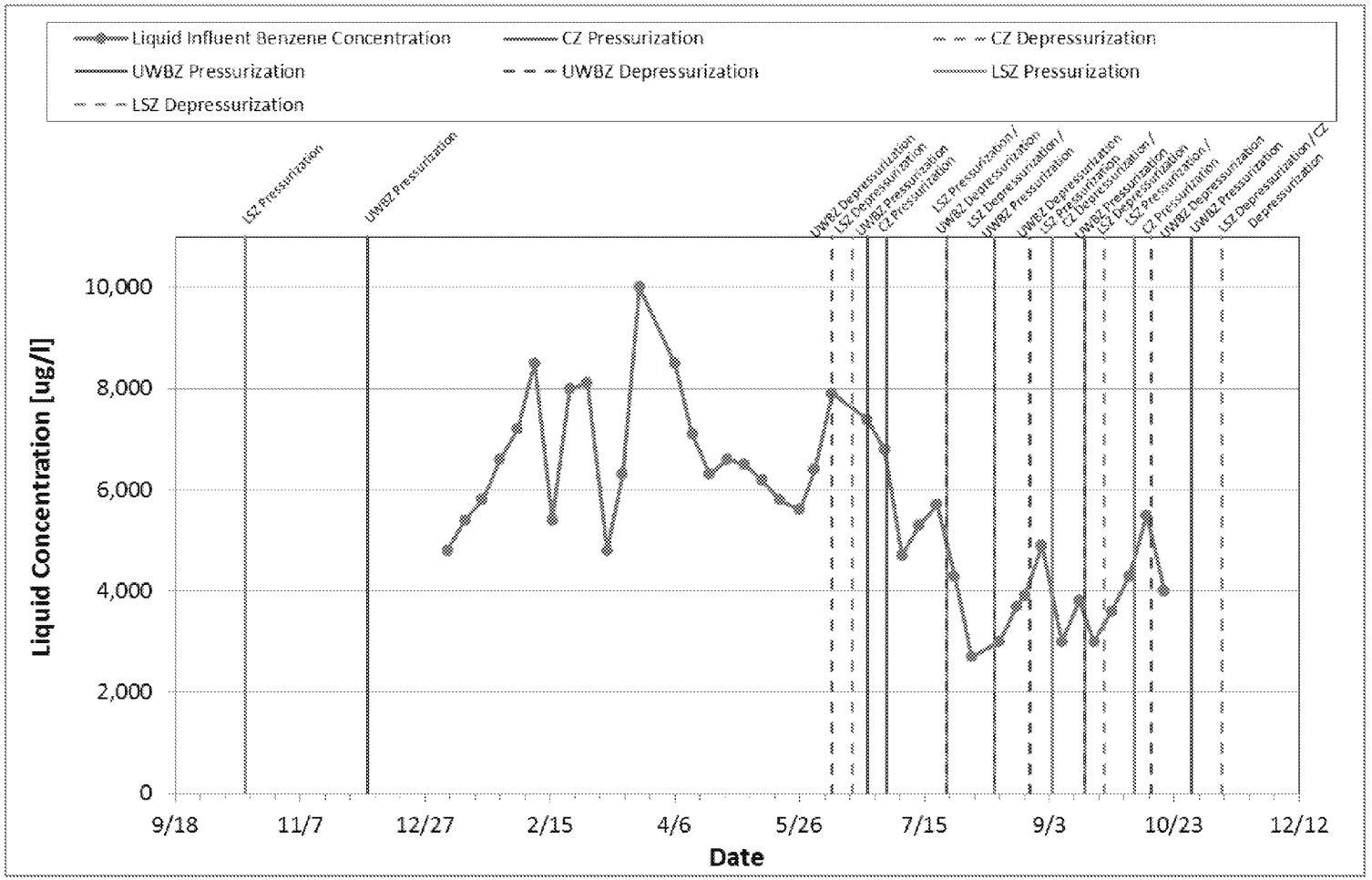
Extracted Vapor Benzene Concentrations over Time
(measured at thermal accelerator influent [includes air stripper effluent] by EPA Method TO-15)



Benzene concentrations have fluctuated during pressure cycling

Pressure Cycling and Benzene Liquid Concentration Over Time

Extracted Liquid Benzene Concentrations over Time (measured at air stripper influent by EPA Method 8260B)



Benzene concentrations have stabilized

Benzene Concentrations in Groundwater and NAPL Delineation

EPA Comment

- ***Analysis: EPA considers 100 µg/l of benzene in groundwater an appropriate target for a successful remediation, and would not support terminating steam treatment before the stated target (100 – 500 µg/l) is reached***

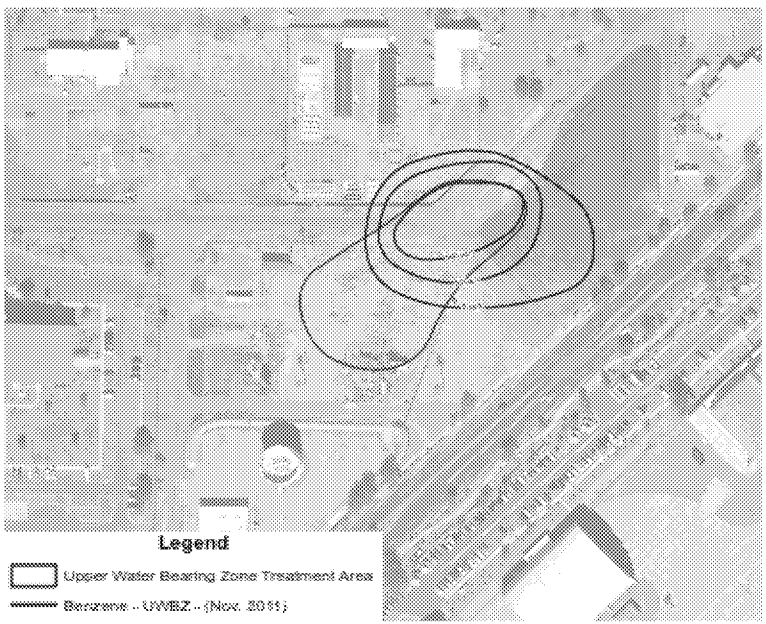
Parameter	Target Criteria	Basis for Target Criteria	Description
Benzene concentrations:	100 to 500 µg/L	Concentration range where natural attenuation can complete degradation within the remedy time frame.	Benzene concentrations in extracted groundwater provide an indication of the amount of benzene remaining in the TTZ. These concentrations will be monitored against a target benzene concentration in the 100 to 500 µg/L range within the TTZ. This concentration range is predicted to achieve cleanup levels within the 20-year remedial timeframe based on modeling of groundwater contaminant attenuation outside the TTZs after active EBR (Appendix E). Benzene located around the perimeter of the TTZ and the perimeter/interior extraction wells will be evaluated for benzene concentrations to identify any perimeter influx that may mask benzene removal within the TTZ. It is expected that lower benzene concentrations within this range will be achieved in the interior of the TTZs than at the perimeter.

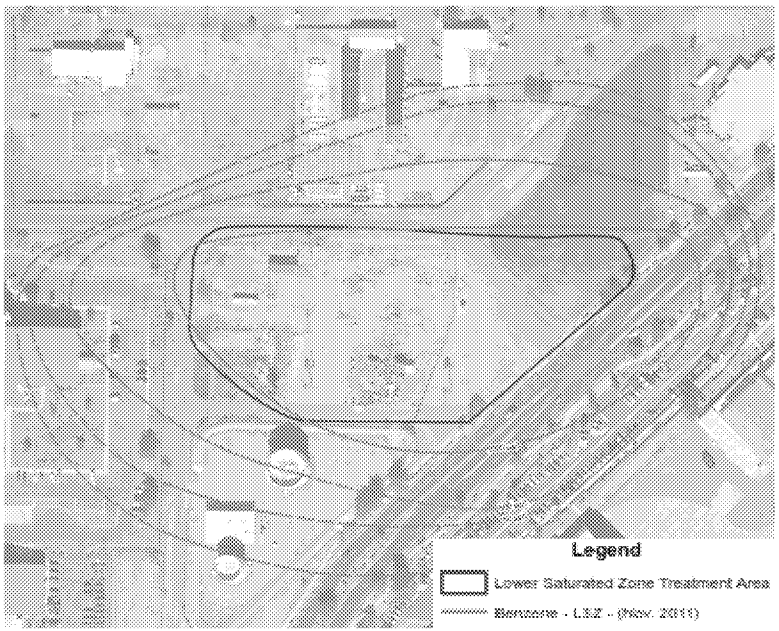
Site ST012 SEE System Benzene Concentrations

- 100 to 500 µg/L was set as the goal for SEE in the interior as the concentration range where natural attenuation can complete complete degradation within the remedy timeframe (20 years post ROD)
- Groundwater concentrations above 500 µg/L expected to remain at TTZ perimeters because of known contamination outside of TTZ.
- Contribution from perimeter likely enhanced by elevated temperatures (increased dissolution and solubility)
- Groundwater concentrations may also be above 500 µg/L in some areas of TTZ interior because of contribution from perimeter groundwater (i.e., extracted groundwater at interior MPE wells originates as a combination of condensed steam and perimeter groundwater that has pulled to the interior)
- Concentrations above 500 µg/L (as high as 5,500 µg/L in RD/RAWP model) in the TTZ can be addressed through EBR
  - Depletion of LNAPL in TTZ interior leaves mainly dissolved phase BETX
  - Sulfate injected at perimeter will migrate and contribute to reductions in TTZ interior
  - EBR treatment of perimeters will reduce further perimeter contributions to TTZ interior
  - Additional sulfate can be injected in TTZ if necessary

Site ST012 Changes in NAPL Interpretation and SEE TTZs Over Time

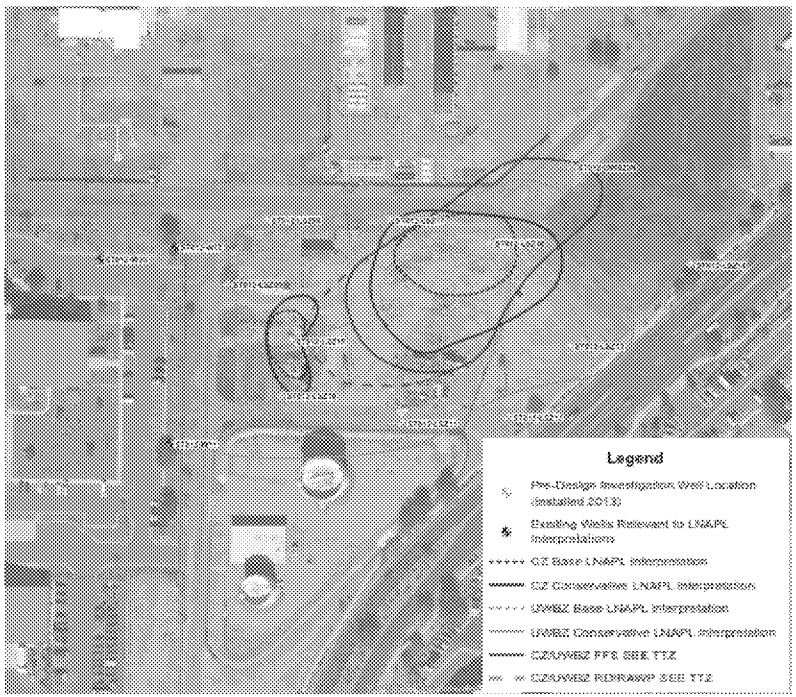
- During FFS SEE TTZs selected based on dissolved benzene at that time
  - In UWBZ extended TTZ to included general areas of TEE pilot
  - In LSZ limited by physical constraints (e.g., Sossaman Road)
  - Benzene concentration within the site limited by available data

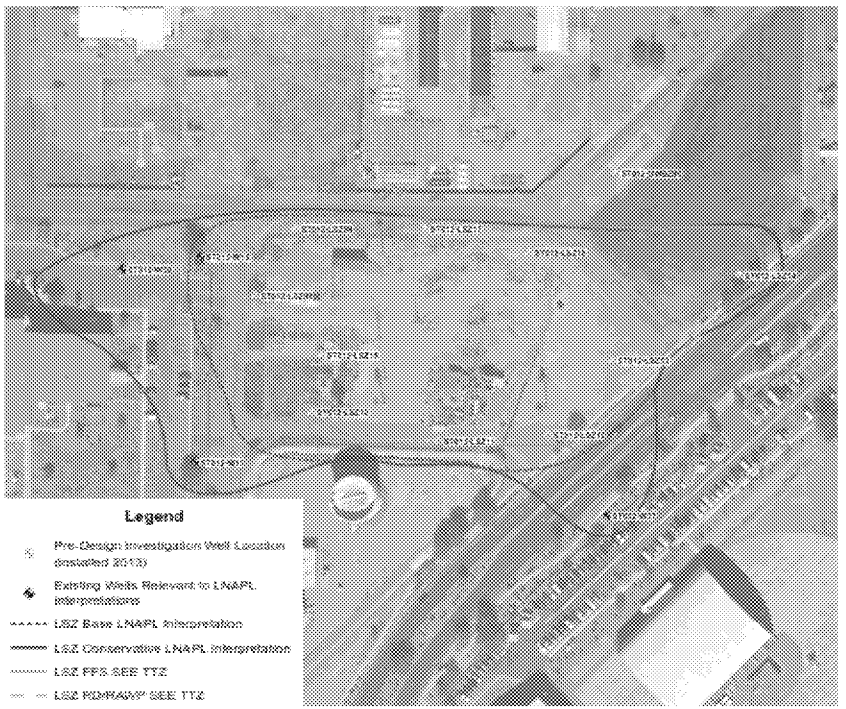




Site ST012 Changes in NAPL Interpretation and SEE TTZs Over Time

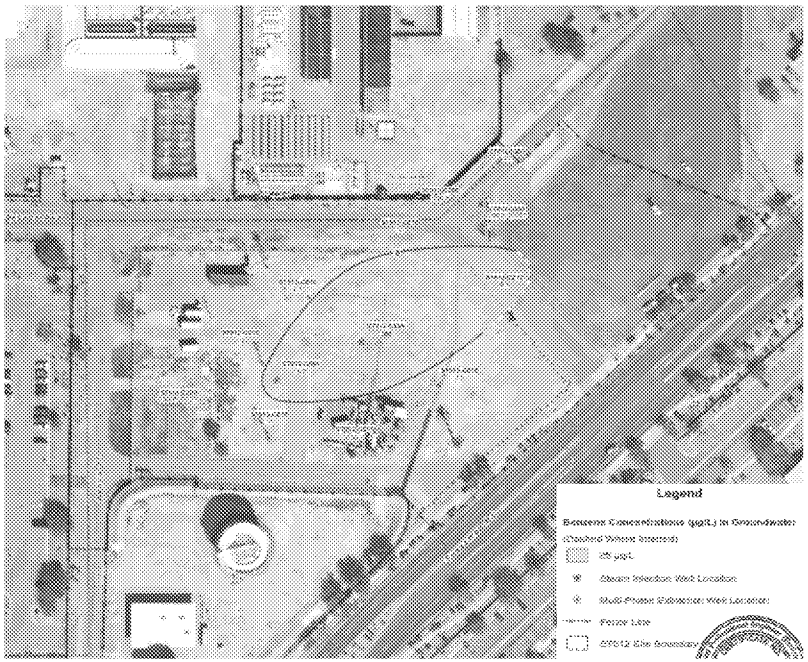
- During PDI/RDRA WP previously selected TTZs updated based on PDI boring data
  - Base and conservative LNAPL extent interpretations
  - CZ/UWBZ and LSZ TTZs expanded on the west
  - Residual NAPL identified outside the TTZs to be addressed in remedy by EBR
  - Proof of concept for EBR to handle residual LNAPL mass in modeling appendix



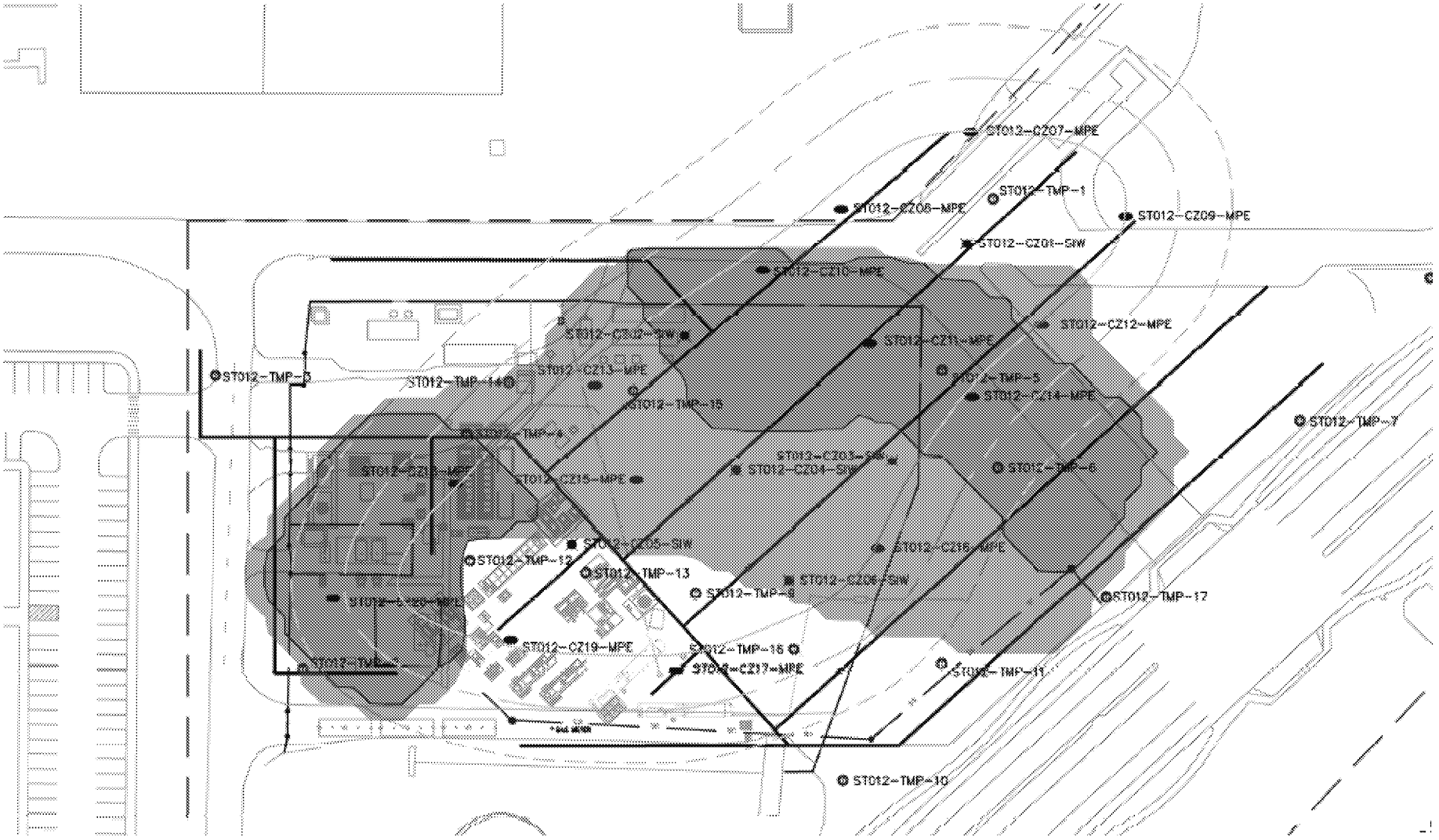


Site ST012 Changes in NAPL Interpretation and SEE TTZs Over Time

- During full-scale SEE construction designed TTZs evaluated based on full-scale well boring data
  - Residual NAPL confirmed outside the CZ TTZ
  - To address areas of heavier NAPL near CZ TTZ, added 1 CZ MPE well to west to increase potential LNAPL recovery
  - No mobile NAPL and low benzene concentrations pre SEE



Cobble Zone – NAPL Delineation during SEE Installation November 2013 – January 2014



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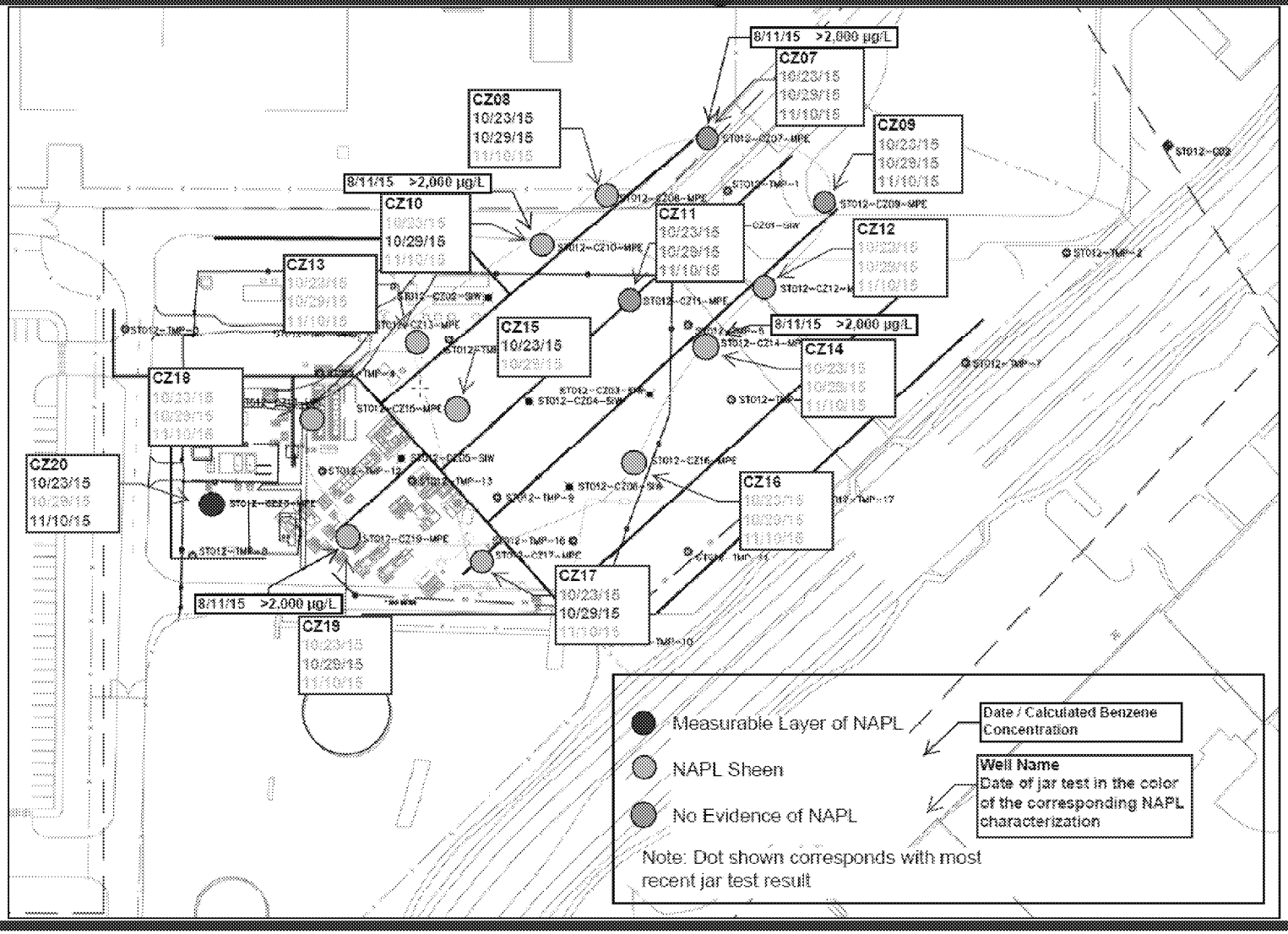
NAPL Screening Results and Calculated Benzene Concentrations – Cobble Zone August – November 2015



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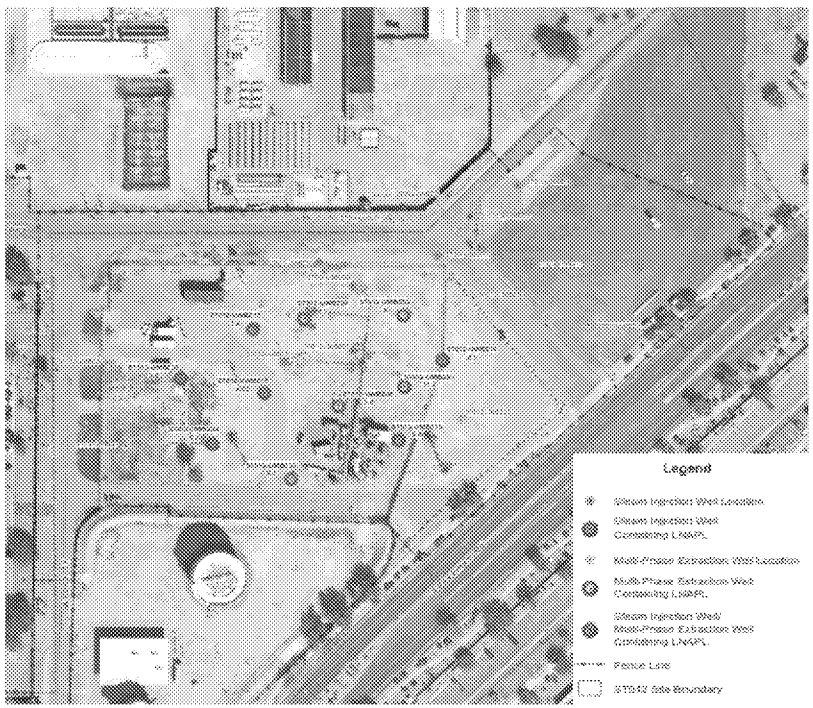
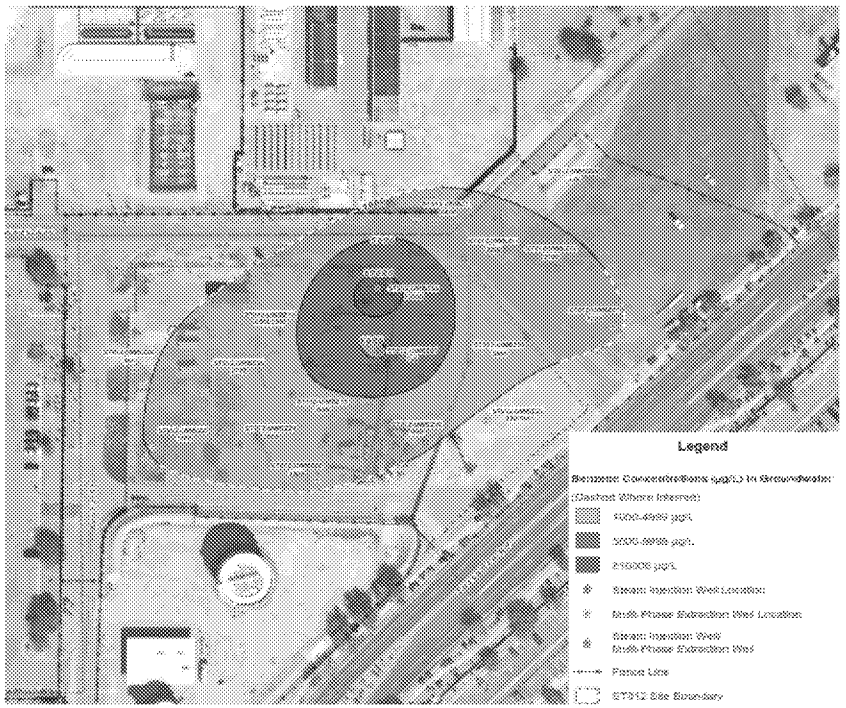
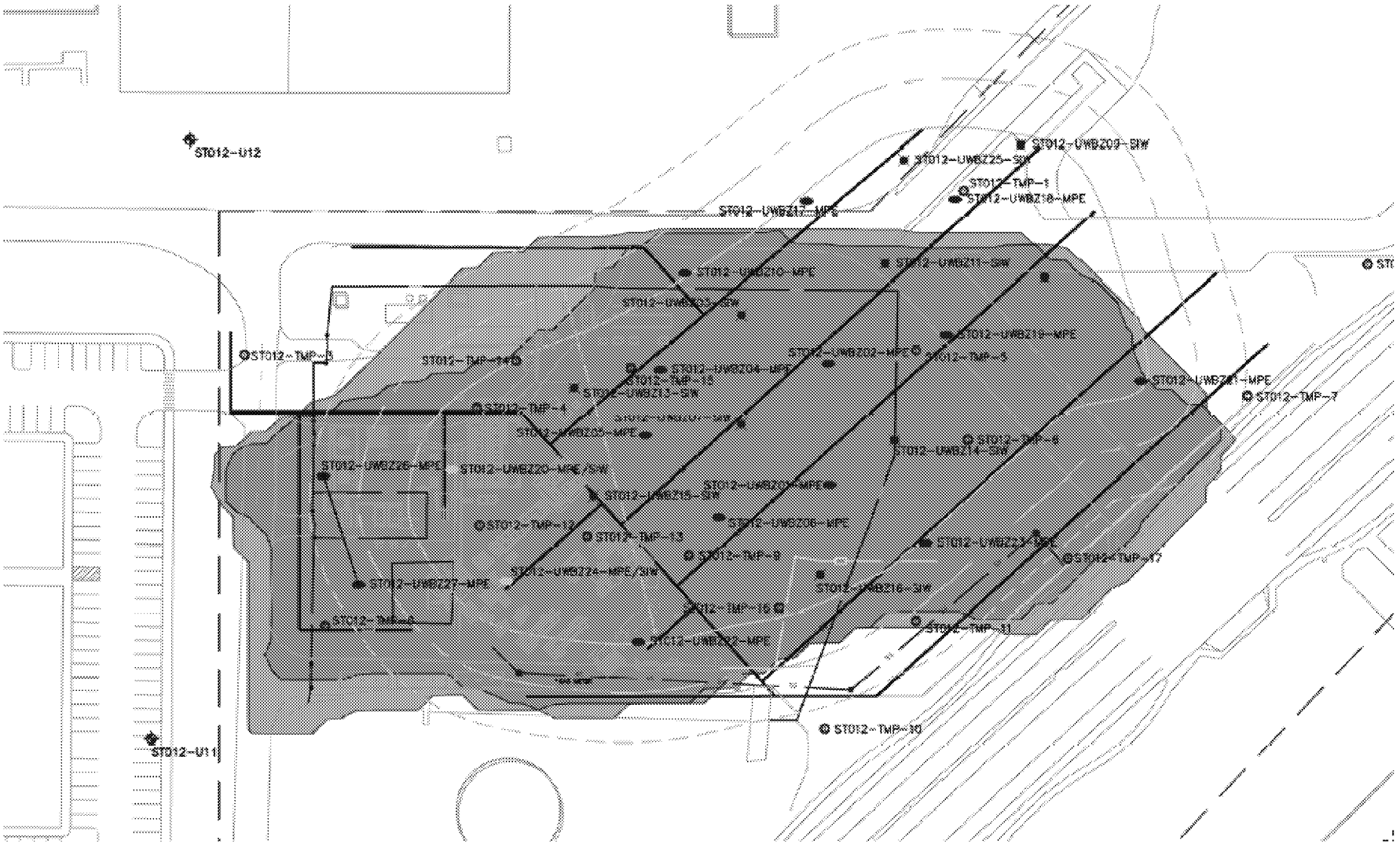
Site ST012 Changes in NAPL Interpretation and SEE TTZs Over Time

- During full-scale SEE construction designed TTZs evaluated based on full-scale well boring data
  - Residual NAPL confirmed outside the UWBZ TTZ
  - To address areas of heavier NAPL near TTZ, added 2 UWBZ MPE wells to west to increase potential LNAPL recovery
  - Converted 2 UWBZ MPE wells in west to dual purpose wells





Upper Water Bearing Zone – NAPL Delineation during SEE Installation November 2013 – January 2014



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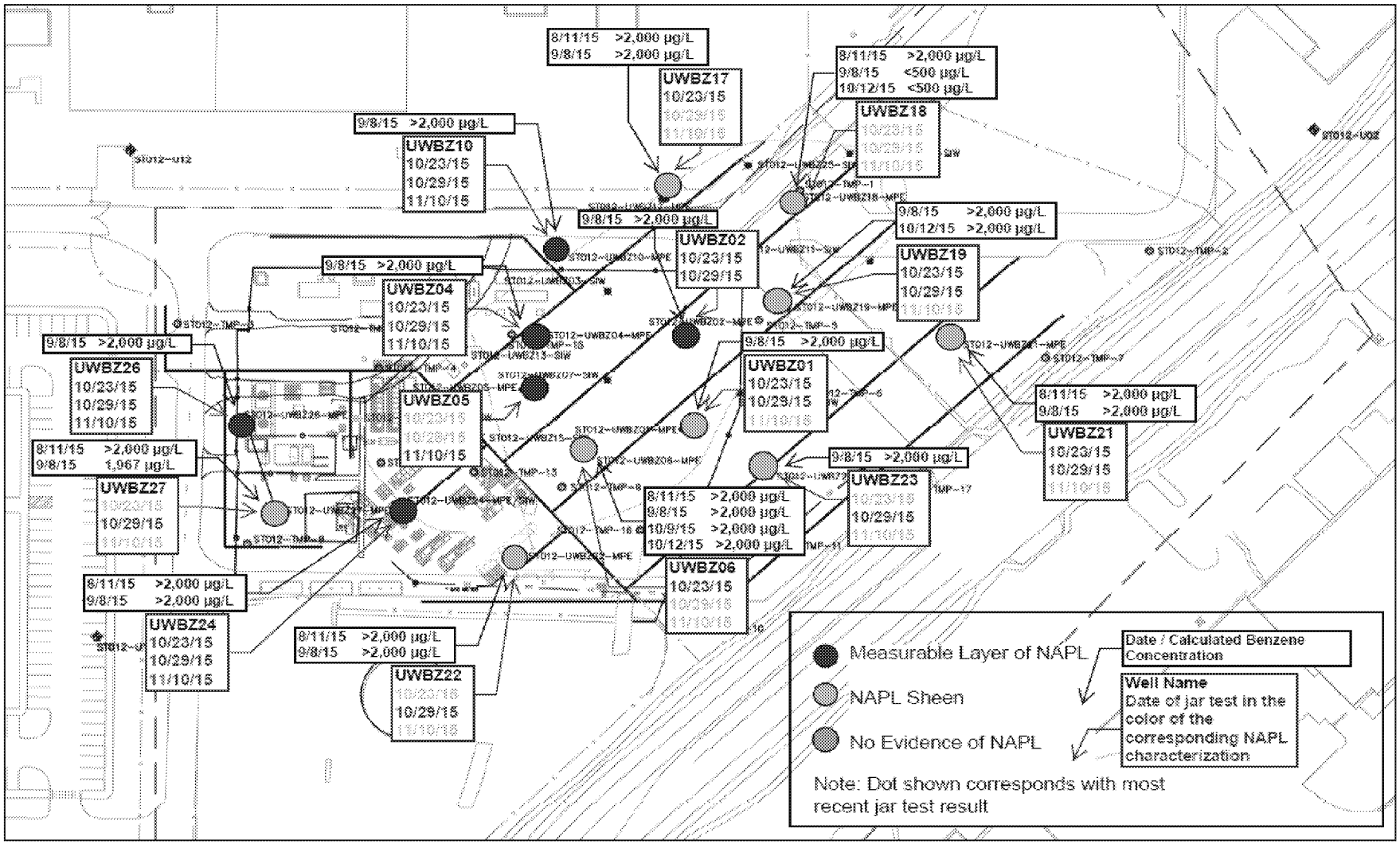
NAPL Screening Results and Calculated Benzene Concentrations – Upper Water Bearing Zone August – November 2015



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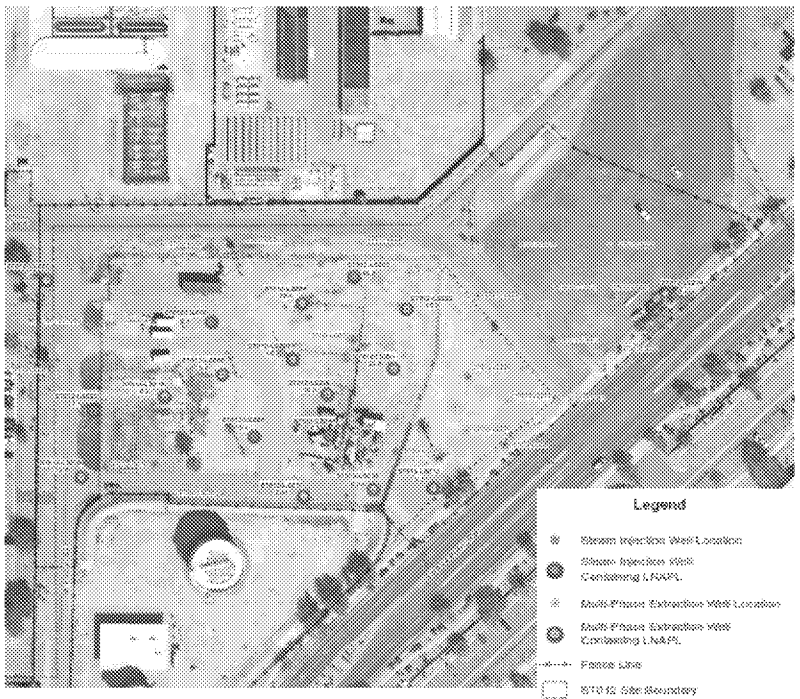
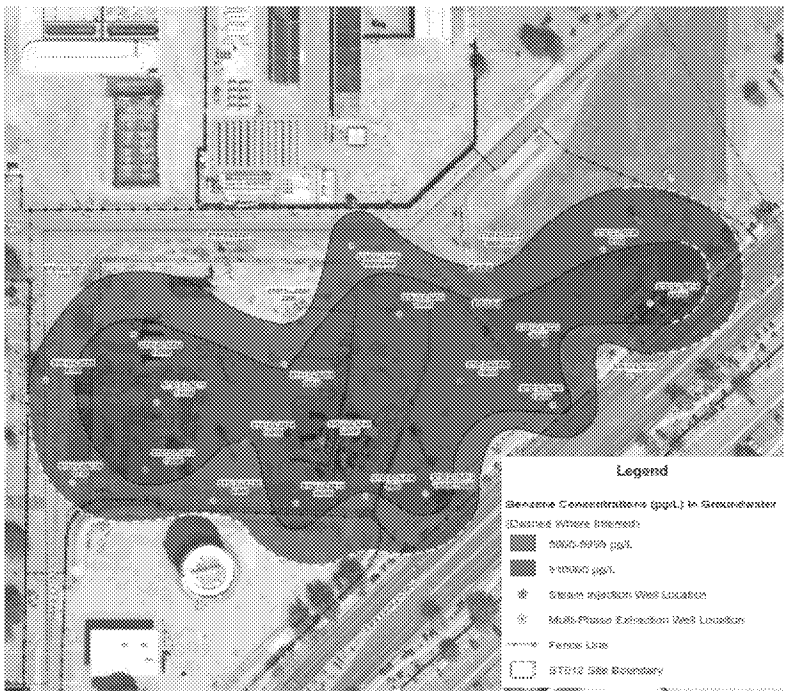
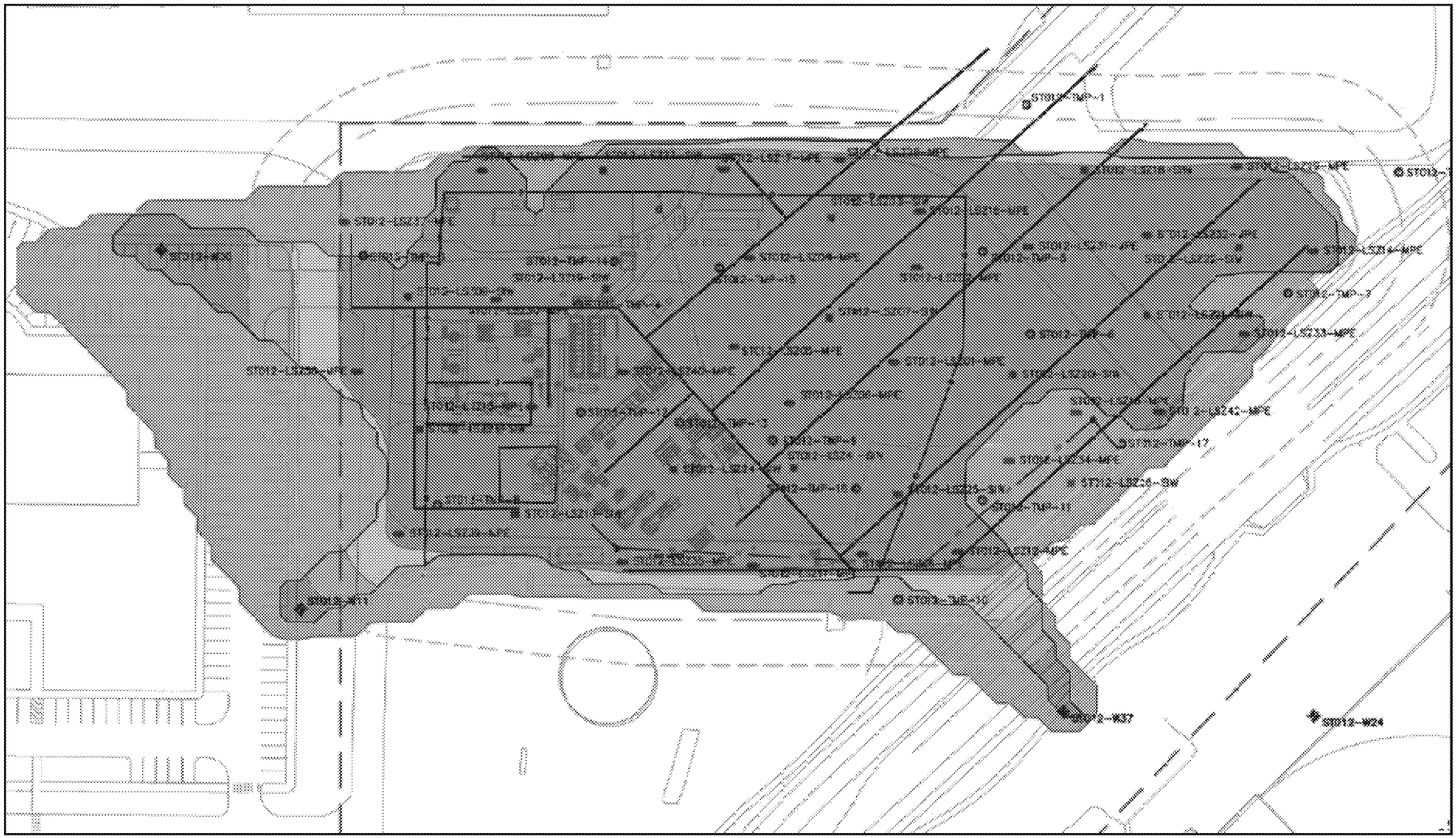
Site ST012 Changes in NAPL Interpretation and SEE TTZs Over Time

- During full-scale SEE construction designed TTZs evaluated based on full-scale well boring data
  - Residual NAPL confirmed at LSZ TTZ perimeter
  - No new wells installed, adjusted SIW and MPE well configuration to avoid pushing steam into NAPL observed near perimeter
  - Highest observed mobile NAPL and benzene concentrations pre SEE





Lower Saturated Zone – NAPL Delineation during SEE Installation November 2013 – January 2014



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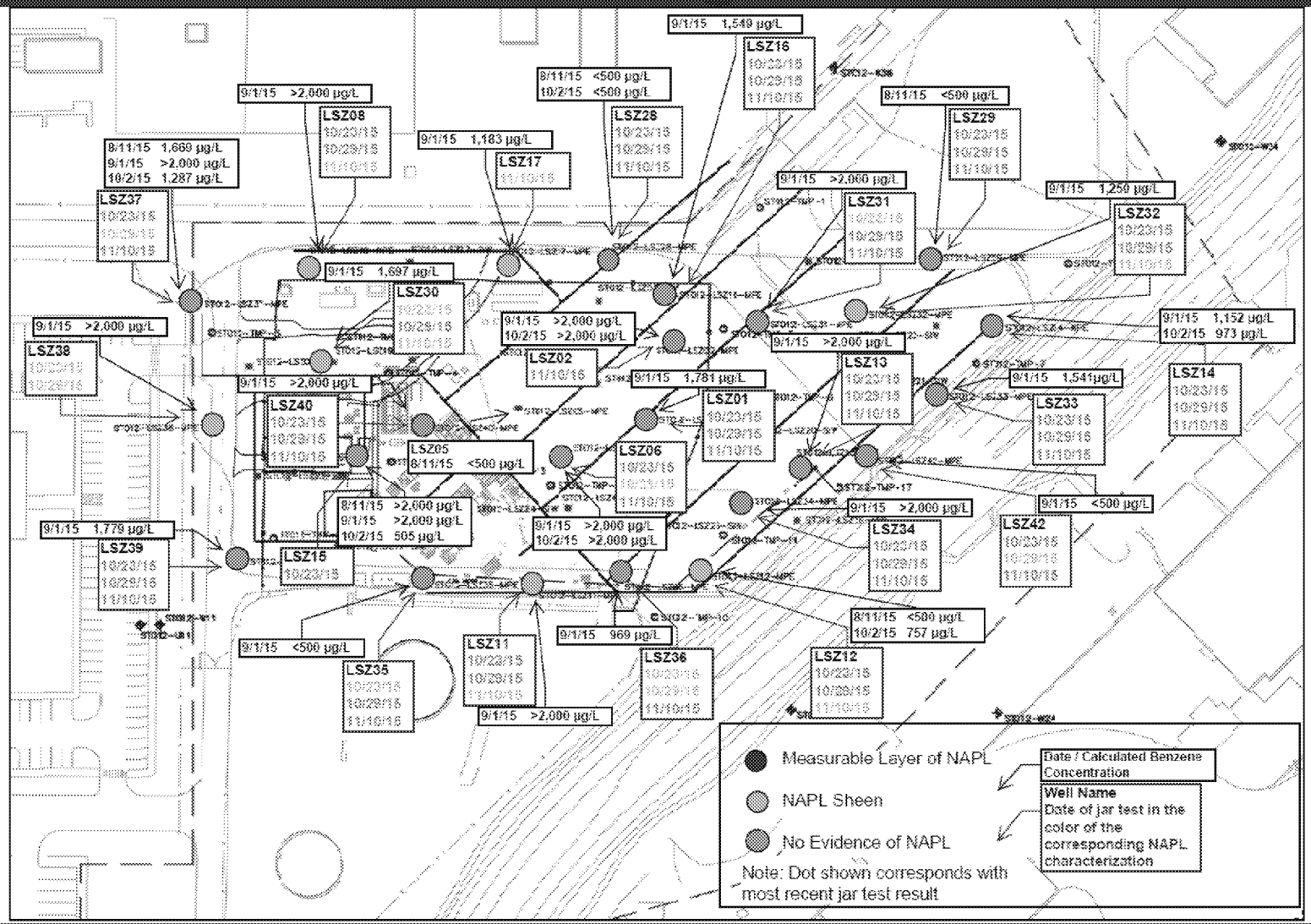
NAPL Screening Results and Calculated Benzene Concentrations – Lower Saturated Zone August – November 2015



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Site ST012 NAPL Interpretation Changes Summary

- Two rounds (PDI/RD/RAWP and during construction) of changes to increase extent of SEE influence were implemented during design and construction
- CZ benzene concentrations pre-SEE already met the EBR transition criteria. They are now higher due to the enhanced solubility of NAPL/benzene. A similar relationship is seen in the UWBZ. LSZ had higher pre-SEE benzene concentrations than other zones but is the most improved.
- LSZ is approaching benzene goals in interior. Continued progress expected in CZ.
- UWBZ had the greatest estimated extent and mass of NAPL outside the TTZ of the three zones. Achievement of benzene concentrations is dependent on perimeter effects and data suggests perimeter influence in UWBZ may be significant. Further treatment of UWBZ needed to validate perimeter influence.
- SEE as a method of removal of NAPL/benzene from beyond the TTZ is much less efficient as from within the TTZ. Transition to EBR, even in the presence of mass removal at the TTZ perimeters, represents a greener remediation approach to the remaining mass than continued extraction by SEE and is consistent with the ROD and the RD/RAWP

Steam Injection

EPA Comment

- ***Analysis: Criteria for amount of steam injection has not been met. The design steam injection rate was based on 1.6 pore volumes of steam injection, which is lower than the commonly used criteria of 2 pore volumes of steam. The projected steam injection should be seen as a minimum amount of steam to be injected.***
- ***Note: Volume of steam injection is identified as a guideline for tracking and is not a transition criterion. No minimum volume established (per Table 4-2 RD/RAWP)***

Parameter	Target Criteria	Basis for Target Criteria	Description
Steam injection (guideline)	319,357,000 lbs	Numerical thermal modeling of TTZs.	A targeted total of 319,357,000 lbs of steam is expected to be injected into the TTZ over the course of operations. This represents an average flushing of the TTZ pore volume of 1.6 pore volumes of steam as water throughout operation. Actual steam required to achieve the other criteria may be more or less than this estimate. Because this parameter does not directly measure remediation performance its primary use will be as a guideline to measure progress compared to the design.

Site ST012 SEE System
SEE to EBR Transition Criteria Progress

Transition Criteria	Progress
Target Temperature Achievement	• CZ: Average target temperature achieved • UWBZ: Average target temperature achieved • LSZ: Average temperature achieved (depths above 235 ft bgs) • Steam breakthrough observed at all interior MPE wells
Pressure Cycling Status	• CZ: Currently in the second pressurization/depressurization cycle • UWBZ: Currently in the fifth pressurization/depressurization cycle • LSZ: Currently in the fourth pressurization/depressurization cycle
Mass Removal Status	• Peak mass removal occurred April – June 2015 (vapor and NAPL phases)
Benzene Concentrations	• Overall decline in dissolved phase benzene concentrations but reaching asymptotic level – perimeter contribution
Steam Injection Status (guideline)	• 257 MM lbs injected versus 320 MM operations guide – lower permeability zones accepting less steam than modeled. • Achieved flushing of 1.5 pore volume versus 1.6 designed – not a NAPL depletion design but a benzene reduction design, thus less than 2 pore volumes seen at other sites • Steam quantity or pore volume flush not a major metric – benzene content in TTZ is (driving polishing phase)

Site ST012 SEE System Path Forward

- Primary transition criteria met (temperatures and mass removal). Pressure cycling ongoing.
- Coordinated pressure cycle ongoing (all zones simultaneously) – will help quantify status for enhance volatilization
- Additional sampling ongoing:
  - Continue ~weekly jar test results
  - Collect groundwater samples in the LSZ in week of 30 Nov
  - Collect groundwater samples in the UWBZ & CZ early to mid Dec
  - Week of 14 Dec – Review and discuss latest data (BCT call 17 Dec.)
  - 31 Dec – Shutdown of steam
- Sample planning is dynamic in response to results received at each round. Changes are likely.

Site ST012
Enhanced Bioremediation (EBR) Update

Site ST012 EBR Design

- EBR RD/RAWP Model Review
- Review of Phase 1 Injection Plan
- Potential Adjustments to Phase 1 Injection Plan based on Jar Test Results
- Preliminary Path Forward for EBR

Site ST012 Overview of EBR Modeling from the RD/RAWP

- EBR modeled by reactive transport numerical model (MODFLOW-SURFACT)
- Source was estimated as LNAPL distribution less:
  - 90% LNAPL removal in the TTZs (except LPZ at 50%)
  - 90% benzene reduction in benzene content from LNAPL within TTZs (except LPZ at 50%)
  - Untreated LNAPL remains outside the TTZs (0% reduction from residual saturation)
- Dissolved benzene concentrations established in the model at solubility (includes concentrations up to 5,500 µg/L)
- Conservative degradation rates assumed
- With adequate supply of sulfate, dissolution rate of LNAPL can be the rate limiting process but model demonstrated ability of EBR to address remaining contamination after SEE including areas of untreated LNAPL outside the TTZs
- Dissolution rate of benzene enhanced by elevated temperatures of SEE (not accounted for in EBR modeling)

Site ST012 Overview of EBR Modeling from the RD/RAWP

- At end of active sulfate EBR, based on modeling, benzene may still be present at concentrations > 1,000 µg/L
- By 2031, the benzene concentrations in each of the hydrostratigrapic zones are predicted to be below 5 µg/L.

Table E-4.15 Predicted Maximum and Average Dissolved Benzene Concentrations Following Sulfate-Reducing EBR

Hydrostratigraphic Zone	Date (month/year)	Predicted Benzene Concentration (µg/L)		Notes
		Average	Maximum	
Cobble Zone	04/2017	21	27	End of EBR Recirculation/TEA Addition
	04/2025	1.25	7.8	~8 years following EBR
	01/2031	0.08	0.95	~15 years following EBR
Upper Water Bearing Zone	04/2017	210	1,400	End of EBR Recirculation/TEA Addition
	04/2025	5.5	9.5	~8 years following EBR
	01/2031	1.0	3.3	~15 years following EBR
Lower Saturated Zone	04/2017	31	270	End of EBR Recirculation/TEA Addition
	04/2025	1.9	6.8	~8 years following EBR
	04/2031	0.64	2.8	~15 years following EBR

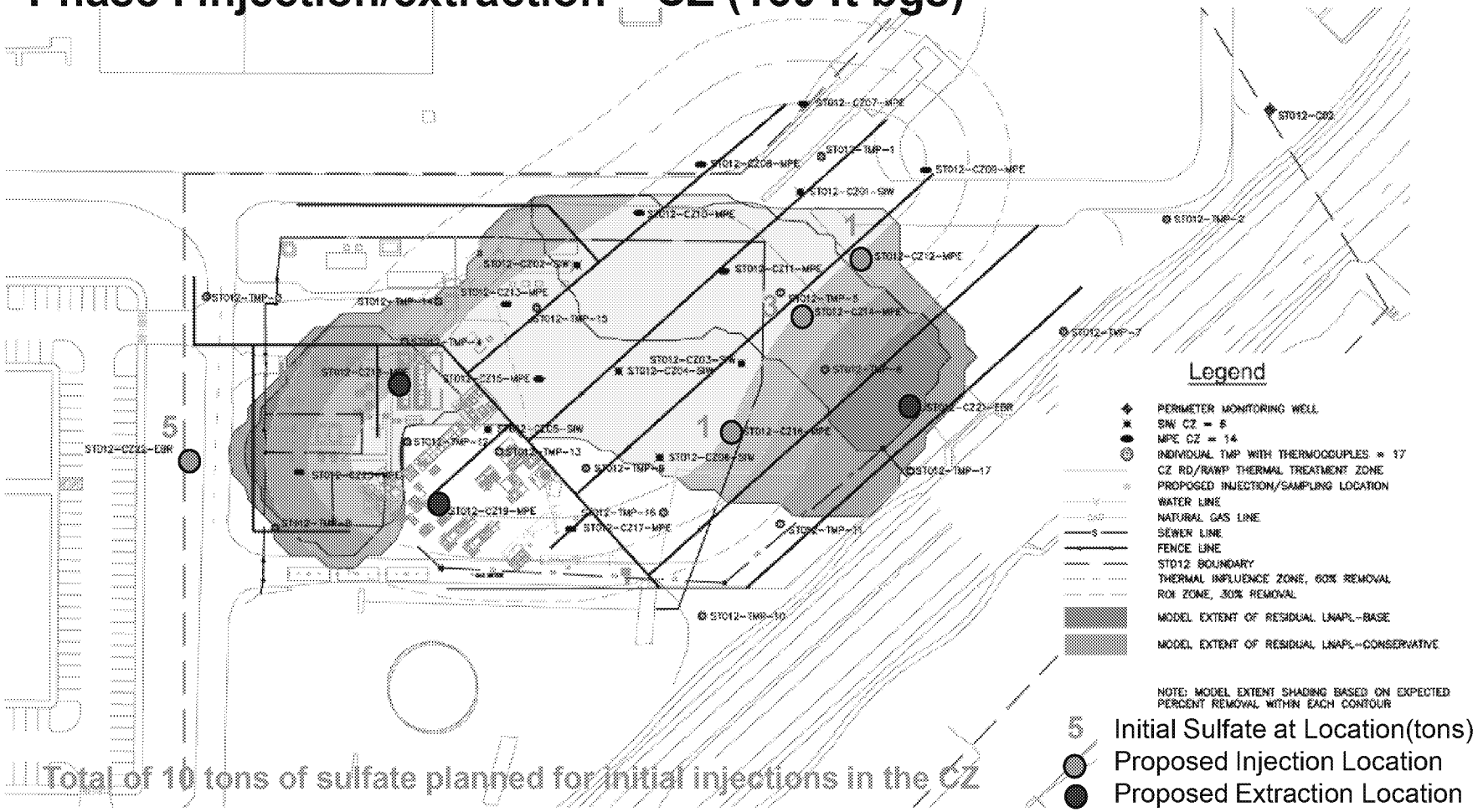
Notes:
~ - approximately
µg/L – micrograms per liter
EBR – enhanced bioremediation
TEA – terminal electron acceptor

Site ST012 EBR Design

- **Preliminary Phase 1 Injections**
  - **Focus on areas of highest mass outside of SEE TTZs**
  - **Use some existing perimeter monitoring wells**
  - **Install additional perimeter wells**
  - **Implement batch injections of sulfate solution in perimeter wells**
  - **Continue extraction from SEE perimeter wells to promote distribution of sulfate solution through contaminated zones**
  - **Monitor conditions and adjust**

Site ST012 EBR Design

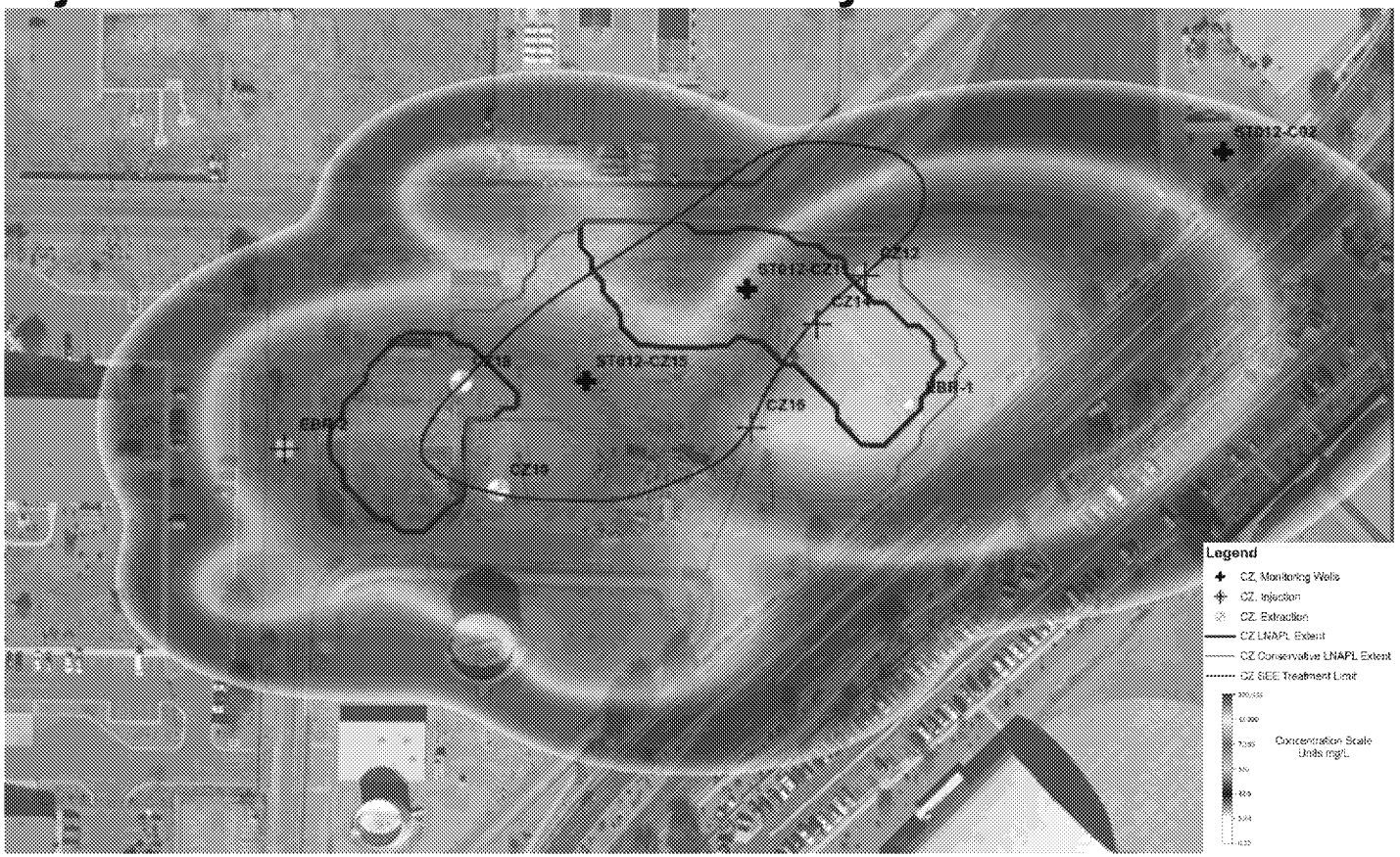
- **Phase I injection/extraction – CZ (160 ft bgs)**



Total of 10 tons of sulfate planned for initial injections in the CZ

Site ST012 EBR Design

- **Sulfate Distribution (without reaction) for Phase I injection/extraction – CZ – 150 days**



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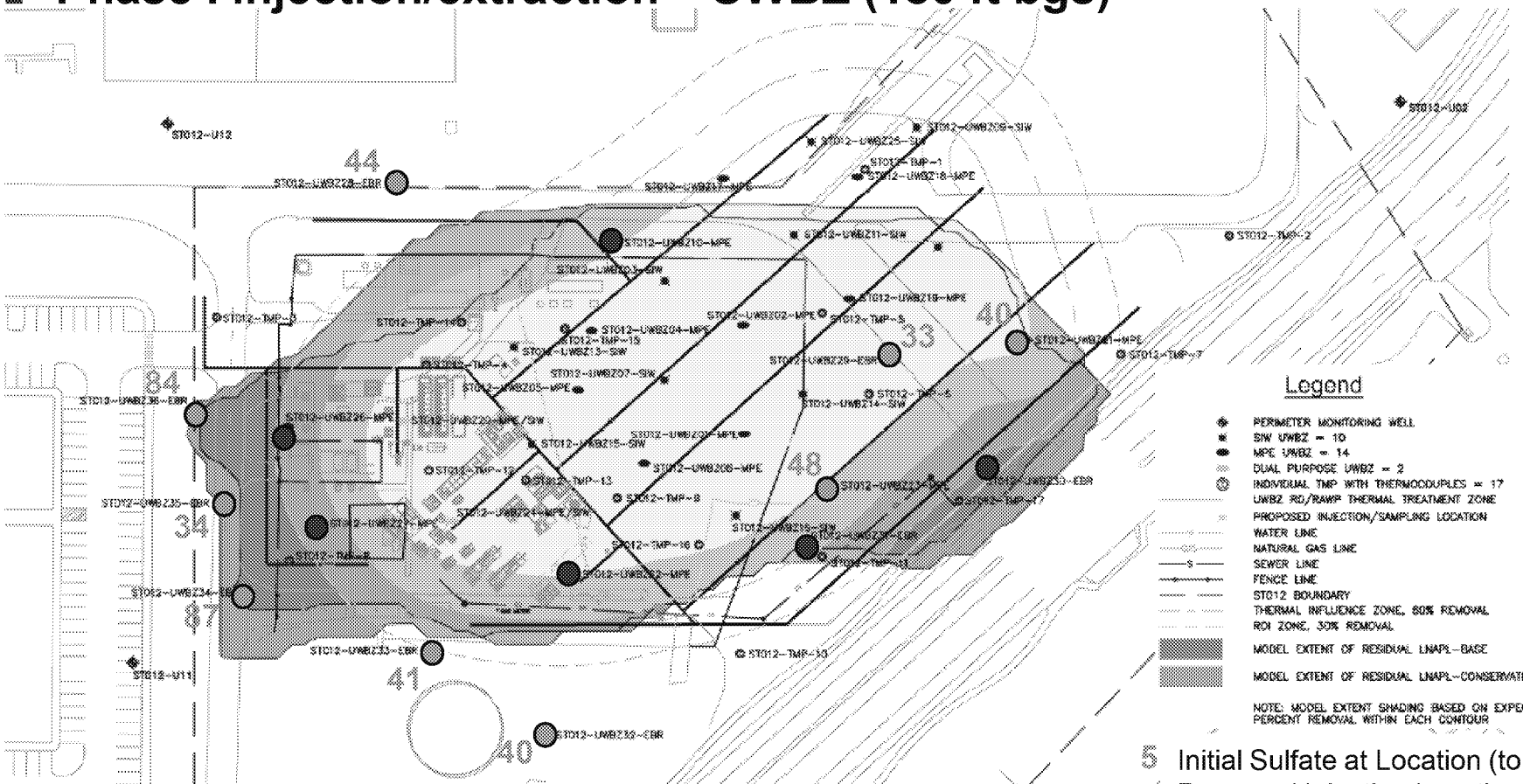
Site ST012 EBR Design

- **Phase I injection/extraction – UWBZ (180 ft bgs)**



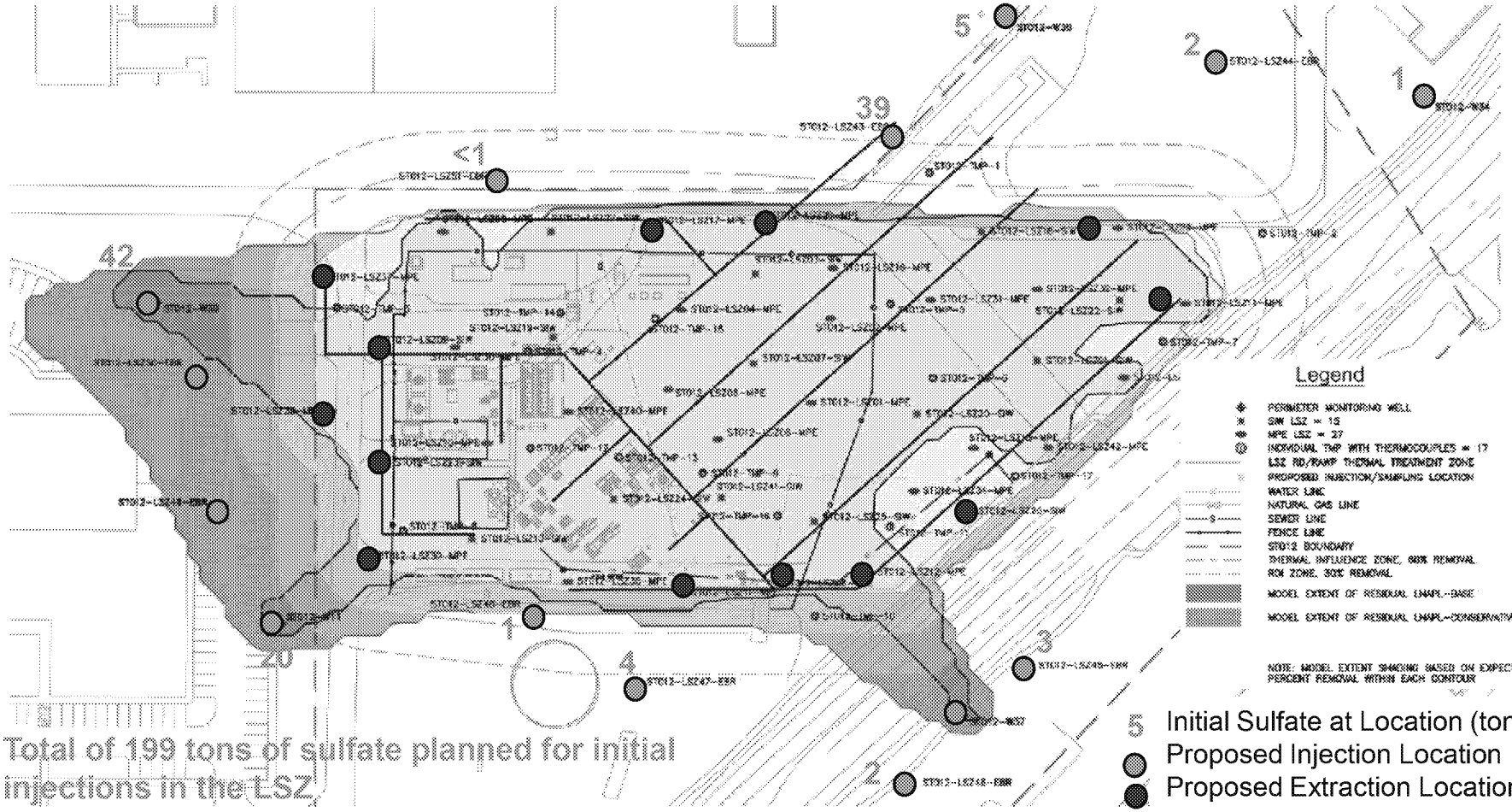
Total of 451 tons of sulfate planned for initial injections in the UWBZ

Site ST012 EBR Design

- **Sulfate Distribution (without reaction) for Phase I injection/extraction – UWBZ – 150 days**

Site ST012 EBR Design

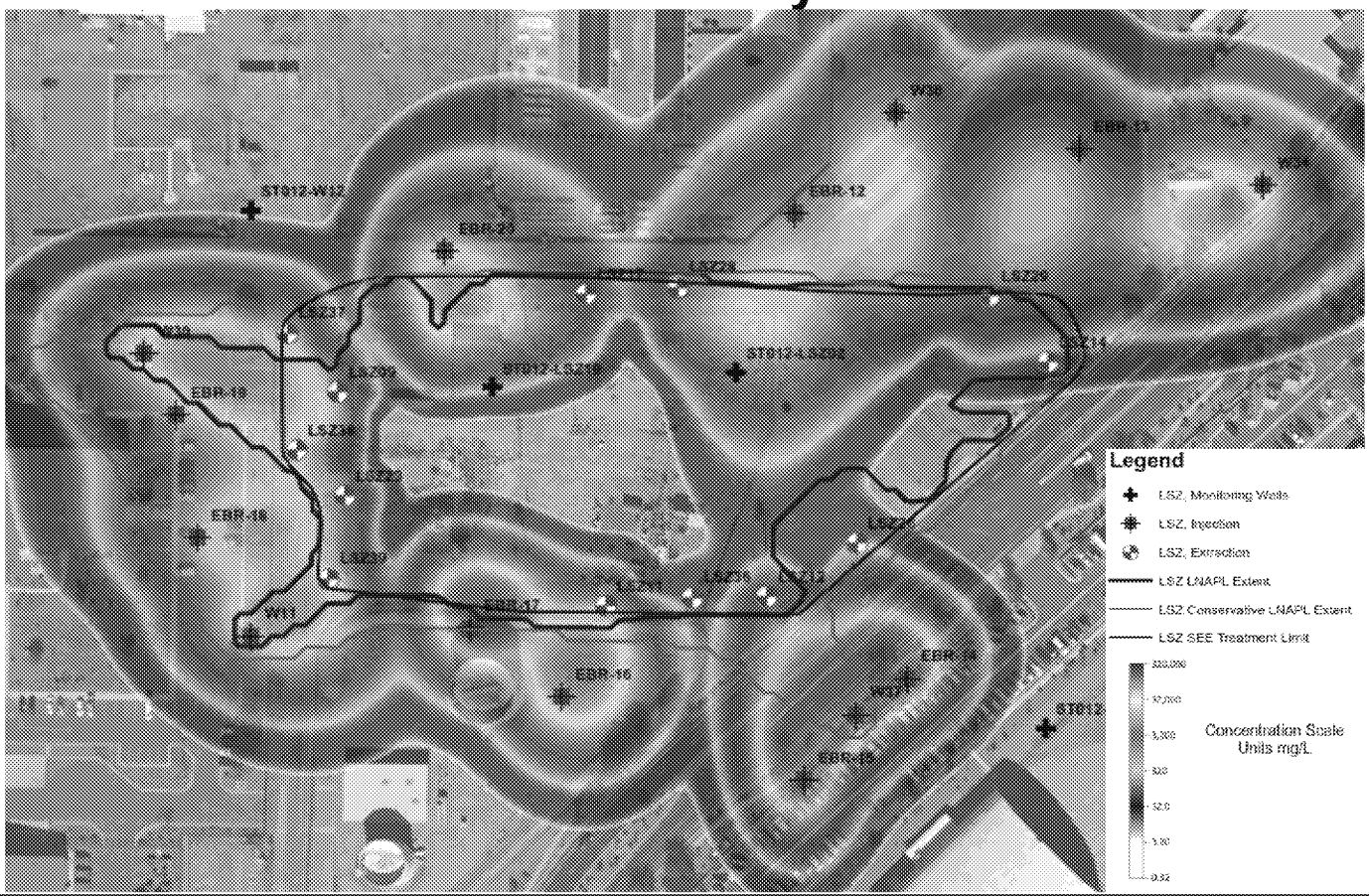
- **Phase I injection/extraction – LSZ (220 ft bgs)**



Total of 199 tons of sulfate planned for initial injections in the LSZ

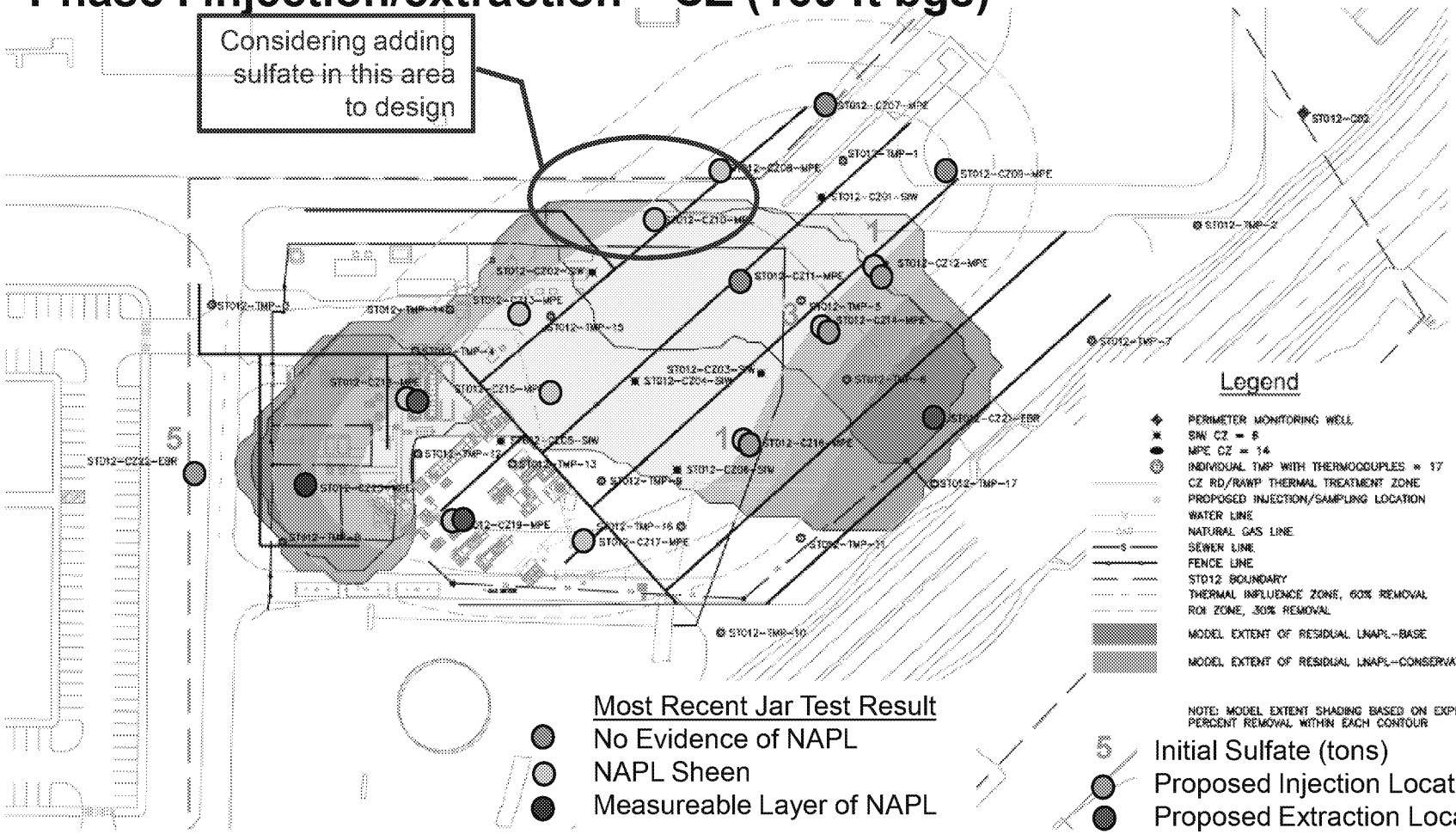
Site ST012 EBR Design

- **Sulfate Distribution (without reaction) for Phase I injection/extraction – LSZ – 150 days**



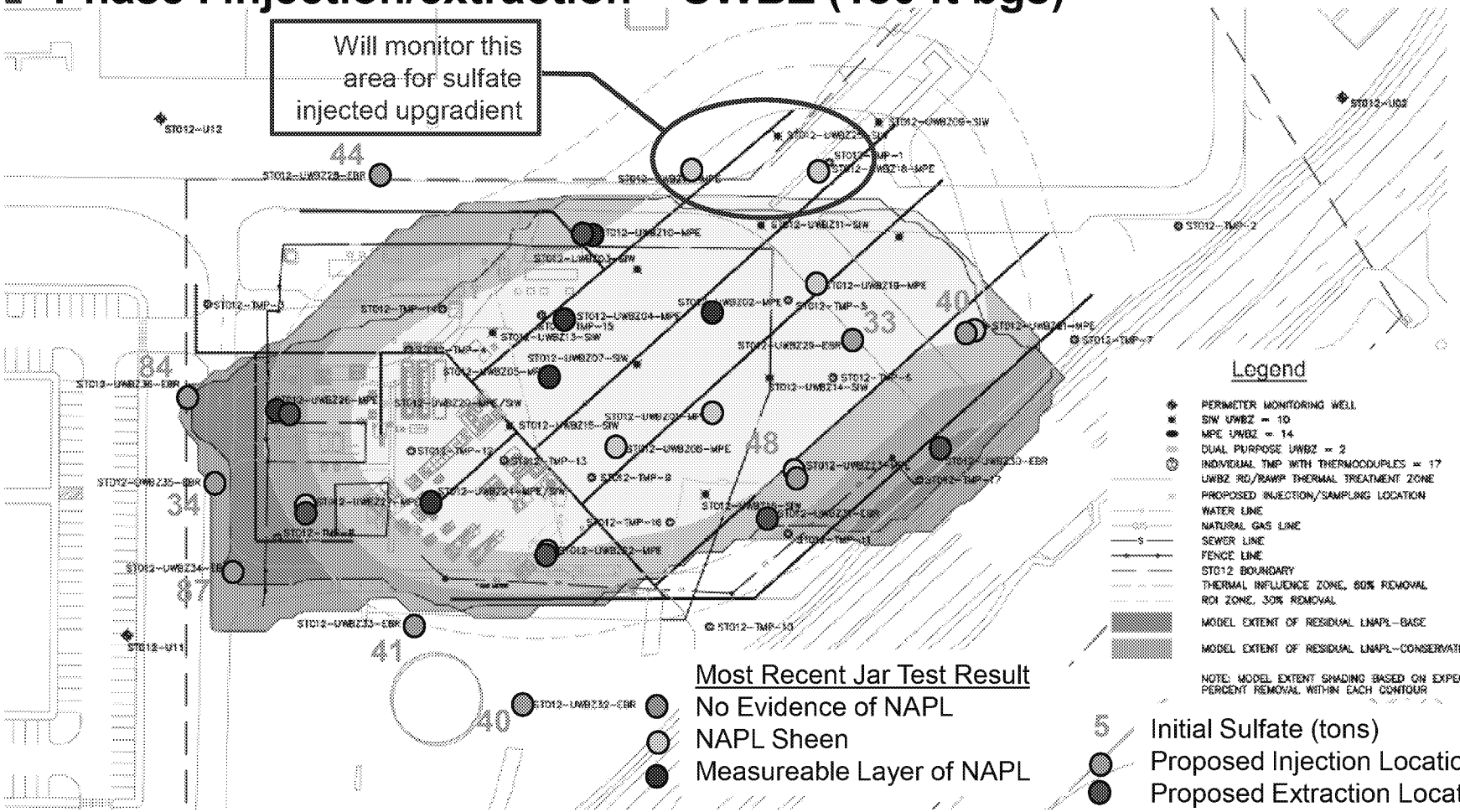
Site ST012 EBR Design and Jar Test Results

- **Phase I injection/extraction – CZ (160 ft bgs)**



Site ST012 EBR Design and Jar Test Results

- **Phase I injection/extraction – UWBZ (180 ft bgs)**



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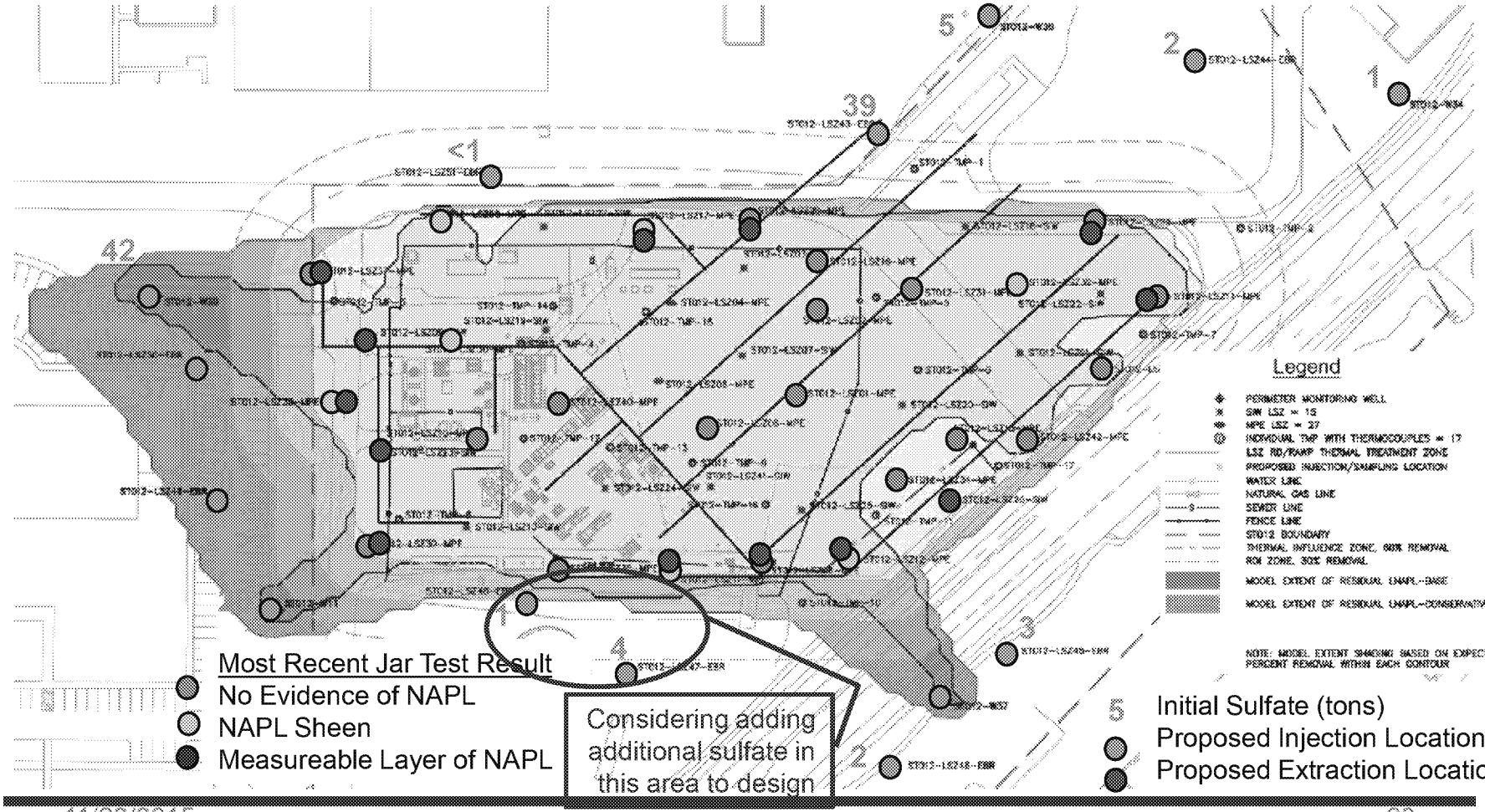
Site ST012 EBR Design and Jar Test Results

- **Phase I injection/extraction – LSZ (220 ft bgs)**



Site ST012 EBR Design

- Path Forward
  - RD/RAWP Addendum #2 for EBR
    - Detail Phase 1
    - Present methods for alternate injection strategies in the future – details of locations and volumes will be presented in future BCT meetings/calls
    - Currently in AF review.
    - Projecting submission of draft on 30 Nov
  - Implement Phase 1
    - Begin drilling in January
    - Injection timing depends on final SEE schedule and drilling completion